

AWS D17.1/D17.1M:2024  
An American National Standard

# Specification for Fusion Welding for Aerospace Applications

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American Welding Society®



AWS D17.1/D17.1M:2024  
An American National Standard

Approved by the  
American National Standards Institute  
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# Specification for Fusion Welding for Aerospace Applications

4th Edition

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Prepared by the  
American Welding Society (AWS) D17 Committee on Welding in the Aircraft and Aerospace Industries

Under the Direction of the  
AWS Technical Activities Committee

Approved by the  
AWS Board of Directors

## Abstract

This specification provides the general welding requirements for welding aircraft and space hardware. It includes but is not limited to the fusion welding of aluminum-based, nickel-based, iron-based, cobalt-based, magnesium-based, and titanium-based alloys using electric arc and high energy beam processes. There are requirements for welding design, personnel and procedure qualification, fabrication, inspection, and acceptance criteria for aerospace, support, non-flight hardware, and crewed spaceflight hardware. Additional requirements cover repair welding of existing hardware. A commentary for the specification is included.





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**This revision of AWS D17.1/D17.1M, *Specification for Fusion Welding for Aerospace Applications*, is respectfully dedicated to the memory of Jagdish (JT) Amin, who served on the AWS D17 Committee on Welding in the Aircraft and Aerospace Industry since 1995.**

**The Committee sadly misses his passion, wisdom, and friendship. His commitment and significant contributions to the advancement of the aerospace industry will live on through this new revision.**

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## Foreword

This foreword is not part of this standard but is included for informational purposes only.

Prior to 1977, aviation welding specifications were primarily dependent on government standards for contract purchases and were based on welding technology from the 1950s. Those specifications were MIL-W-8611 (steel), MIL-W-8604 (aluminum), MIL-W-18326 (magnesium), and MIL-T-5021 for welder performance requirements. In 1977, the aviation and aerospace industry and government moved to update some of these standards by consolidating the welder's performance of MIL-T-5021 into MIL-STD-1595. MIL-STD-1595 was issued as a supplement to the ASME Section IX code in 1977. It was subsequently revised and superseded by MIL-STD-1595A in 1983. The first update to the 1950's welding process specifications came with the release of MIL-W-8604A in 1982, almost 30 years after its initial release. The material welding specifications MIL-W-8604, MIL-W-8611, and MIL-W-18326 were consolidated into MIL-STD-2219 in 1988 and represented the most significant change to aviation welding standards in more than 30 years.

After two unsuccessful attempts to change the military standards, the American Welding Society contacted the industry and proposed a meeting to develop a national specification. Interested welding personnel from the aviation industry gathered in the autumn of 1993 to lay the foundation for a national aviation and aerospace specification for fusion welding to replace MIL-STD-1595A and MIL-STD-2219. This meeting led to the formation of the AWS D17 Committee on Welding in the Aircraft and Aerospace Industries. The overriding theme the welding committee members brought to the table was that the aviation industry had changed. Those changes affected the welding processes and procedures, base metal and filler metal types, quality, and the inspection equipment, just to name a few. Since the 1950s, the welding specifications had not completely kept pace during the revision process to reflect those technology changes. The writing of this specification was a prime opportunity for the industry and government to create a document to include those changes. Through an industrial effort and committee consensus, this specification represents several years of work, bringing the aviation and aerospace industry together to acknowledge the technological advances of welding and materials. Included in this document is weld repair technology to enable the use of weld repair beyond those areas originally designated for a weld.

Changes to this fourth edition of D17.1 include the following:

In this fourth edition of D17.1, the committee made several fundamental changes to expand the use and applicability of the document for the dynamics within the industry. The criteria for welding procedure and welder qualification in Clause 5 were separated for clarity and to prevent mixing of elements. As part of this, Tables 5.1 through 5.7 were reworked for better organization and to isolate each of the requirements to a single element. Also, for qualification coupon configuration, figures were added to integrate the criteria more completely within the D17.1 specification; allowing for more independence from the external documents such as AWS B2.1.

For Non-Flight Hardware in Clause 9, the criteria for fluid service inspection was diverted to ASME B31.3.

Clause 10 is a new addition which addresses the unique criteria for Crewed Spaceflight Hardware.

Underlined areas in text indicate an addition and vertical lines adjacent to text, figures, tables, and equations indicate where changes (additions, modifications, corrections, deletions) from the 2017 edition were made.

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# Specification for Fusion Welding for Aerospace Applications

## 1. General Requirements

**1.1 Scope.** This specification contains requirements for fusion welding and nondestructive examination (NDE) of aerospace flight hardware as well as for the welding and NDE of non-flight hardware. When this specification is stipulated in contract documents, conformance with all provisions of the specification shall be required, except for those provisions specifically exempted or modified by the Engineering Authority or contract documents.

The following is a summary of the specification clauses:

Clause 1. **General Requirements:** basic information on the scope and provisions of this specification.

Clause 2. **Normative References:** a listing of the documents that are required for the application of this specification.

Clause 3. **Terms and Definitions:** a list of technical terms and definitions of particular importance to this specification.

Clause 4. **Design of Welded Connections:** requirements and guidance information for the design of welded connections.

Clause 5. **Welding Procedure and Performance Qualification:** qualification requirements for welding procedures, welders, welding operators, and tack welders.

Clause 6. **Fabrication:** requirements for preparation, assembly, and workmanship when welding aerospace hardware.

Clause 7. **Inspection:** criteria for inspector qualification, responsibilities of inspectors, acceptance of production welds, and standard requirements for performing visual inspection and nondestructive examination (NDE).

Clause 8. **Repair of Existing Structures:** requirements for repair of existing aerospace flight hardware.

Clause 9. **Nonflight Hardware:** requirements for welding nonflight hardware.

Clause 10. **Crewed Spaceflight Hardware:** Requirements in addition to baseline flight hardware welding requirements addressing the fabrication and inspection of crewed spaceflight hardware and launch vehicles.

**1.1.1 Flight Hardware.** The purpose of this specification is to provide requirements for commonly used fusion welding processes, materials, and acceptance criteria for production welds. This specification also provides requirements for materials, processes, and acceptance criteria that are not listed in this specification when approved by the Engineering Authority.

**1.1.1.1 Aircraft, Rotorcraft, and Engines Subject to Federal Aviation Administration (FAA) Regulation.** When applying welding in the design, construction, and repair of aircraft, rotorcraft, or engines subject to FAA regulation, the Engineering Authority must perform the appropriate design analyses and impose process control measures that will ensure compliance with the applicable requirements of the Code of Federal Regulations, Title 14.

**1.1.2 Nonflight Hardware.** Nonflight hardware, tooling, ground support equipment, and related nonconventional aerospace facilities shall be designed and welded in accordance with the requirements of Clause 9.

**1.1.3 Crewed Spaceflight Hardware.** Crewed spaceflight hardware, including launch vehicles, shall be fabricated and inspected per the additional requirements found in Clause 10. This clause may be invoked for uncrewed missions if directed by the Engineering Authority.

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**1.2 Units of Measure.** This standard makes use of both U.S. Customary Units and the International System of Units (SI). The latter are shown within brackets ( [ ] ) or in appropriate columns in tables and figures. The measurements may not be the exact equivalents; therefore, each system must be used independently.

**1.3 Safety.** Safety and health issues and concerns are beyond the scope of this standard and therefore are not addressed herein.

Safety and health information is available from the following sources:

American Welding Society:

- (1) ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*
- (2) AWS Safety and Health Fact Sheets
- (3) Other safety and health information on the AWS website

Material or Equipment Manufacturers:

- (1) Safety Data Sheets supplied by materials manufacturers
- (2) Operating Manuals supplied by equipment manufacturers

Applicable Regulatory Agencies

Work performed in accordance with this standard may involve the use of materials that have been deemed hazardous, and may involve operations or equipment that may cause injury or death. This standard does not purport to address all safety and health risks that may be encountered. The user of this standard should establish an appropriate safety program to address such risks as well as to meet applicable regulatory requirements. ANSI Z49.1 should be considered when developing the safety program.

**1.4 Classification.** All welds produced in accordance with this specification shall be classified on the engineering drawings or contract. Weld classifications shall be as follows: Class A, Class B, or Class C. These classifications refer to the level of inspection required and to the applicable acceptance criteria. Alternate acceptance criteria and inspection methods shall be applied if specified on the engineering drawing. A weld joint may be zoned with multiple classifications.

**1.5 Approval.** All references to the need for approval shall be interpreted to mean approval by the Engineering Authority.

**1.6 Mandatory Provisions and Authority.** Nothing in this specification supersedes applicable laws and regulations unless a specific exemption has been obtained prior to the contract date or as a contract amendment.

**1.6.1 Mandatory Provisions.** Most provisions of this specification are mandatory when the use of this specification is invoked. Certain provisions are optional and apply only when specified in contractual documents for a specific project. Guidance information is indicated by the words "should" or "may."

**1.6.2 Drawing Authority.** When requirements in this specification conflict with those on the engineering drawing, the requirements on the engineering drawing shall take precedence.

**1.6.3 Specification Authority.** In the event of a conflict between the text of this specification and the references cited herein, the text of this specification takes precedence.

**1.7 Design Definition and Requirements.** This specification recognizes that the Engineering Authority may convey its design definition and accompanying requirements for a weldment using one or a combination of recognized formats and media. Examples range from an engineering drawing, an engineering specification, digital engineering models, and the contract. When this specification invokes the engineering drawing(s) or contract, it is inclusive of these other recognized formats and media.

**1.8 Exclusions.** In-process welding of castings at the fabricating foundry is outside the scope of this specification. This exclusion covers the in-process welding, the qualification of the personnel performing those in-process welds, and the qualification of the procedures for those in-process welds.



## 2. Normative References

The documents listed below are referenced within this publication and are mandatory to the extent specified herein. For undated references, the latest edition of the referenced standard shall apply. For dated references, subsequent amendments or revisions of the publications may not apply since the relevant requirements may have changed.

American Welding Society (AWS) documents:

*AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination;*

*AWS A3.0M/A3.0, Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying;*

*AWS A5.1/A5.1M, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding;*

*AWS A5.5/A5.5M, Specification for Low Alloy Steel Electrodes for Shielded Metal Arc Welding;*

*AWS A5.20/A5.20M, Specification for Carbon Steel Electrodes for Flux Cored Arc Welding;*

*AWS A5.29/A5.29M, Specification for Low Alloy Steel Electrodes for Flux Cored Arc Welding;*

*AWS B2.1/B2.1M, Specification for Welding Procedure and Performance Qualification;*

*AWS B5.2, Specification for the Training, Qualification, and Company Certification of Welding Inspector Specialists and Welding Inspector Assistants;*

*AWS D1.1/D1.1M, Structural Welding Code — Steel;*

*AWS QC1, Specification for AWS Certification of Welding Inspectors.*

Aerospace Industries Association (AIA) document:

*NAS 410, NAS Certification & Qualification of Nondestructive Test Personnel.*

American Society for Testing and Materials (ASTM) documents:

*ASTM E164, Standard Practice for Ultrasonic Contact Testing of Weldments;*

*ASTM E1417/E1417M, Standard Practice for Liquid Penetrant Testing;*

*ASTM E1444/E1444M, Standard Practice for Magnetic Particle Testing;*

*ASTM E1742/E1742M, Standard Practice for Radiographic Examination;*

*ASTM E29, Standard Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications.*

Society of Automotive Engineers (SAE) documents:

*AMS-H-81200, Heat Treatment of Titanium and Titanium Alloys;*

*AMS2680, Electron Beam Welding for Fatigue Critical Applications;*

*AMS2801, Heat Treatment of Titanium Alloy Parts.*

## 3. Terms and Definitions

AWS A3.0M/A3.0, *Standard Welding Terms and Definitions*, provides the basis for terms and definitions used herein. However, the following terms and definitions are included below to accommodate usage specific to this document. Refer to Annex H for a list of commonly used acronyms in this standard.

**aerospace flight hardware.** Any portion of a flight vehicle (e.g., aircraft, missile, spacecraft) or its payload.

**complex weld joint.** A continuous weld joint with variations in section thickness and tapered transitions that may require changes in welding position or direction, weld deposition rates, and heat inputs during the execution of a weld. A complex weld joint cannot be defined on the engineering drawing by a single welding symbol.

**critical structure.** A structure or component in which a single failure would cause significant danger to personnel, loss of system, loss of major component, loss of control, unintentional release of critical stores, inability to release armament stores, result in an operating penalty or loss of the aerospace system, or abortion of the mission.

**customer.** The individual or organization which established the mission or design requirements of a product and provides some form of compensation for the delivery of the product. The product could be an engineering design, a structure, a system, or a weldment.

**Engineering Authority.** The Engineering Authority is the contracting agency or corporate organization that acts for and on behalf of the customer on all matters within the scope of this standard. The Engineering Authority has the responsibility for the structural integrity or maintenance of airworthiness of the hardware and compliance with all contract documents.

**fabricator.** The organization responsible for producing weldments that satisfy the design and contract requirements.

**fail safe.** A part is defined as fail safe if it can be shown by analysis or test that, due to structural redundancy, the structure remaining after failure of the one part can sustain the new limit loads with an ultimate factor of safety equal to or greater than 1.0, and the remaining structure has sufficient fatigue life to complete the mission.

**filler metal alloy.** A recognized designation of a nominal alloy composition from a recognized industry organization (examples AA4043, ER321, Ti-6Al-4V).

**fracture critical.** A part which, by fracture mechanics analysis, has a service life factor of less than an engineering-defined factor times the vehicle life cycle requirements and failure of which would cause loss of the mission, vehicle, or crew. Also, a part that is a pressure vessel or a rotating machinery component.

**in-process welding of casting.** Welding performed in the foundry on castings. Generally, this type of welding applies to the correction of casting discontinuities.

**Material Review Board (MRB).** A customer or Engineering Authority activity to review and formally disposition nonconforming hardware. MRB typically has the authority to take exception to engineering requirements, which includes authorizing repairs.

**nonconventional aerospace facilities.** Nonconventional aerospace facilities are program-oriented or experimental in nature and may include, but not be limited to, launch complexes, test stands, wind tunnels, operational or research facilities, towers, and similar special purpose facilities whose structures are characterized by unusual or inadequately defined loading conditions, a lack of design precedent, or frequent modifications to support changes in the operational requirements.

**noncritical structure.** A structure or component which is noncritical and is contained so that failure will not affect other flight elements or personnel.

**nonstandard materials.** Base metals and/or filler metals not covered by industrial welding codes or specifications.

**qualification variable.** One of a set of elements that define the qualification limits of a welding procedure specification or of welders, welding operators, or tack welders.

**safety critical item.** A component whose failure will result in probable loss of the aircraft or hazard to personnel due to direct part failure or by causing other progressive part failures.

**sheet.** A generic product form and descriptor used in this specification for planar metal products typically described in the market as sheet metal when thinner and plate when thicker.

**semicritical structure.** A structure or component, the single failure of which would reduce the overall efficiency of the system, but a loss of the system or danger to personnel would not be experienced.

**structures.** Structures are defined by the Engineering Authority according to accepted practices and shall have the same meaning herein.

**tube.** A generic product form and descriptor used in this specification for cylindrical metal products with a hollow centerline. These metal products are typically described in the market as tube when possessing a thinner wall and pipe when possessing a thicker wall.

**UNS number.** The Unified Numbering System (UNS) is a composition-based system of commercial materials. Each metal is indicated by a letter that is followed by five numbers.



## 4. Design of Welded Connections

**4.1 Scope.** The Engineering Authority shall design the weldment and define the requirements to ensure compliance with all mission and system requirements. The engineering documentation shall clearly define special requirements, such as fracture critical, or safety critical, imposed over and above the general requirements. Further, the Engineering Authority shall define process controls and substantiate that all design requirements can be met by welds produced in accordance with specified procedure, fabrication, and inspection requirements. Annex A contains further guidance on the weld joint design and analysis.

**4.2 Weldment Design Data.** The Engineering Authority shall develop or obtain appropriate material property data to support the weldment design. In addition, the Engineering Authority is responsible to account for the residual stresses resulting from the welding process or providing a method for controlling/minimizing residual stresses, such as annealing or aging after welding.

### 4.3 General Drawing Requirements

**4.3.1 Drawing Information.** Essential information for all welds shall be completely described in the engineering drawing or in referenced supporting documentation. When necessary, the engineering drawing shall show the profile (cross section) of a complex weld joint with sufficient detail for the fabricator to determine essential features at any position along the length of the weld.

**4.3.2 Groove Welds.** All groove welds, including those in flanged butt and corner joints, shall be full penetration (complete joint penetration) unless otherwise specified on the engineering drawing or in the referenced supporting documentation.

**4.3.3 Fillet Welds.** Fillet weld size shall be specified on the engineering drawing. Unless otherwise indicated, the specified size is a minimum with the default maximum size listed in Table 7.1. Fillet weld root penetration shall not be included in weld strength calculations unless a combination groove and fillet weld is specified for the joint.

**4.3.4 Essential Information.** For all welds, the engineering drawing or referenced supporting documents shall specify this specification and the following:

- (1) base metal alloy and condition at the time of welding (e.g., annealed, normalized)
- (2) filler metal alloy, classification, or composition or autogenous weld (without filler)
- (3) postweld thermal treatment, method, or heat treatment cycles (including tensile strength or hardness values as applicable)
- (4) welding symbols per AWS A2.4
  - (a) weld location and extent of welding
  - (b) final weld contour and weld finishing requirements (as welded or subsequently finished)
  - (c) Special conditions shall be fully explained by added notes or details on the engineering drawing
- (5) weld classifications (Class A, B, or C)
- (6) weld sequence and technique when necessary to control shrinkage stresses and distortion
- (7) dimensional controls required to assure final drawing dimensions
- (8) alternate inspection methods and acceptance criteria where applicable

*NOTE: Unless indicated otherwise, dimensions on the weldment drawing indicate the final dimensions of the weldment and do not include allowances for shrinkage.*

**4.3.5 Inspection Requirements.** The engineering drawings shall define weld inspection requirements. Clause 7 specifies default inspection requirements based on classification, which may be modified as appropriate by the Engineering Authority. A single weld may utilize more than one set of inspection requirements through the use of separate zones applied to the weld.

## 5. Welding Procedure and Performance Qualification

**5.1 General.** This clause establishes the requirements for welding procedure specification data, welding procedure qualification, and qualification, requalification, and maintenance requirements for welders, welding operators, and tack welders.

**5.1.1 Qualification Responsibility.** The fabricator shall be responsible for the qualification of welding procedures and personnel. Qualifications, certifications, requalifications, and recertifications given under this specification do not transfer from one fabricator to another. Properly documented welding procedure specifications (WPSs), procedure qualification records (PQRs), and personnel qualifications qualified under the provisions of this specification by a company that later has a name change due to voluntary action, separation from, or consolidation with a parent company may utilize the new name on its WPS, PQR, and personnel qualification documents while maintaining the supporting qualification records with the old company name.

**5.1.2 Content and Format of Welding Documents.** The WPS, PQR, and performance qualification record shall contain all the required data to appropriately characterize the welding procedure, record procedure qualification, and record welder or welding operator qualification. The specific format is optional. Sample forms are shown in Annex E. In all cases, it is the responsibility of the fabricator to ensure that all required data and welding information is included on all welding documents and records.

**5.1.3 Previously Qualified Welding Procedures and Welders/Welding Operators.** WPSs, PQRs, and performance qualifications that were written and qualified to previous editions of this specification need not be revised or requalified, within the limits specified herein.

**5.1.4 Referee Interpretation of NDE Results.** When NDE indications in test welds are indeterminate (i.e., neither clearly acceptable nor clearly rejectable), a referee examination path is available as approved by the Engineering Authority. Referee examination may include supplementary testing consisting of metallographic examination, bend testing, or both, at the indeterminate indication location, regardless of material group. The Engineering Authority shall define the test method(s) and acceptance criteria for the referee examination.

### 5.2 Welding Procedure Data and Qualification.

**5.2.1 Written WPS.** All welds produced to the requirements of this specification shall be accomplished in accordance with a written WPS. A WPS shall include the welding data shown in Table 5.1 for the relevant welding process.

*NOTE: The WPS may list variables recorded on the PQR within the full range permitted for a qualification variable and practical limits determined by the fabricator for non-qualification variables.*

**5.2.2 Qualification of Welding Procedures.** WPSs for Class A and B welds shall have a supporting PQR. WPSs for Class C welds and tack welds do not require a supporting PQR. Welders or welding operators that successfully complete the procedure qualification, as stated in 5.3.3, shall concurrently be given their performance qualification for that activity. With the approval of the Engineering Authority, AWS B2.1 may be used for welding procedure qualification. WPSs qualified to a higher weld class may also be used to produce welds at a lower weld class within the limitations of Table 5.2

**5.2.2.1 Standard Method of Welding Procedure Qualification.** Unless otherwise specified by the Engineering Authority, WPSs for Class A and Class B welds shall be qualified by performing a welding procedure qualification test weld and recording the actual values on a PQR. The qualification variables for a welding procedure qualification test weld are as shown in Table 5.2 for each of the welding processes. A change in a welding procedure variable beyond the limits shown in Table 5.2 requires a new procedure qualification.

**5.2.2.2 Test Methods for Welding Procedure Qualification.** The tests listed in Table 5.3 are required for welding procedure qualification. When mechanical testing is required by the Engineering Authority, the test coupon shall be of sufficient size to yield the necessary test specimens. Multiple test coupons may be produced if necessary to yield the required test specimens.

(1) See Figures 5.5, 5.6, 5.7, and 5.8 for test coupon configuration.

(a) Figure 5.5 for groove test welds in sheet

(b) Figure 5.6 for fillet test welds in sheet

(c) Figure 5.7 for groove test welds in tube

(d) Figure 5.8 for fillet test welds in tube

(2) All test results shall be recorded on the PQR.

(3) Test welds shall be inspected in accordance with the test methods and acceptance criteria for the applicable weld class per Table 7.1. A 0.5 in [13 mm] discard may be taken at the ends of groove and fillet weld coupons in sheet.

(4) Metallographic examination of fillet welds shall be performed using a magnification of 5X – 100X. All required surfaces shall be evaluated to the relevant acceptance criteria in accordance with Table 7.1 and Figures 5.11, 5.12, 5.13, and 5.14.

**5.2.2.3 Alternative Methods of Procedure Qualification.** In lieu of Clause 5.2.2.1, alternative procedure qualification shall be accomplished. The Engineering Authority shall specify the test weldment configuration, the test methods, and acceptance criteria for the test weldments to be used when qualifying welding procedures using these alternative methods. The following provides examples of alternative configurations for procedure qualification:

- (1) A simulated weld joint sample.
- (2) An actual part.
- (3) An applicable qualification test weld.
- (4) A special test weldment.
  - (a) Simulated service test weldment.
  - (b) Prototype structural special test weldments.
  - (c) Non-loaded special test weldments.



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**Table 5.1**  
**Welding Procedure Specification Variables**

| <b>JOINT DESIGN</b>                                                                                       | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
|-----------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------------|----------------------|----------------------|
| (1) Joint type(s) qualified, including dimensions, and fitup requirements                                 | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (2) Treatment of backside, including method of gouging/preparation                                        | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| (3) Backing material, if used                                                                             | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| <b>BASE METAL</b>                                                                                         | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (4) Base metal alloy                                                                                      | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (5) Thickness range qualified                                                                             | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (6) Diameter range qualified (tubular only)                                                               | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (7) Coating description or type, if present                                                               | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| <b>FILLER METAL</b>                                                                                       | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (8) Specification, classification, alloy, or nominal composition                                          | X                          | X                          | O                          | O                    | O                    | X                          | O                    | O                    |
| (9) Filler metal size or diameter                                                                         | X                          | X                          | O                          | O                    | O                    | X                          | O                    | O                    |
| (10) Supplemental filler metal, including specification and size                                          | O                          | O                          | O                          | O                    | —                    | —                          | O                    | O                    |
| (11) Filler metal feed rate                                                                               | —                          | —                          | O                          | O                    | —                    | —                          | O                    | O                    |
| (12) Consumable insert, including material and type                                                       | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| (13) Hot filler metal amperage                                                                            | —                          | —                          | O                          | O                    | —                    | —                          | O                    | O                    |
| (14) For cladding and hardfacing: the minimum surfacing thickness                                         | O                          | O                          | O                          | O                    | —                    | O                          | O                    | O                    |
| <b>POSITION</b>                                                                                           | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (15) Welding positions(s) allowed                                                                         | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (16) Progression for vertical welding                                                                     | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| <b>PREHEAT AND INTERPASS TEMPERATURE</b>                                                                  | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (17) Minimum preheat temperature                                                                          | X                          | X                          | X                          | X                    | —                    | X                          | X                    | X                    |
| (18) Method of preheat maintenance                                                                        | X                          | X                          | X                          | X                    | —                    | X                          | X                    | X                    |
| (19) Interpass temperature maximum, if applicable                                                         | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| <b>POST WELD HEAT TREATMENT</b>                                                                           | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (20) PWHT including specification or temperature, time, method, and heating/cooling rates when applicable | O                          | O                          | O                          | O                    | O                    | O                          | O                    | O                    |
| <b>SHIELDING GAS</b>                                                                                      | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (21) Torch shielding gas, including composition and flow rate range                                       | X                          | X                          | X                          | X                    | —                    | —                          | —                    | X                    |
| (22) Backing gas, including composition and flow rate range                                               | O                          | O                          | O                          | O                    | —                    | —                          | —                    | O                    |
| (23) Supplemental shielding gas, including composition and flow rate range                                | —                          | O                          | O                          | O                    | —                    | —                          | —                    | O                    |
| (24) Environmental shielding (i.e. purge chamber, gas composition, purity)                                | —                          | O                          | O                          | —                    | —                    | —                          | —                    | O                    |
| (25) Vacuum pressure                                                                                      | —                          | —                          | —                          | —                    | —                    | —                          | X                    | O                    |

(Continued)



**Table 5.1 (Continued)  
Welding Procedure Specification Variables**

| <b>ELECTRICAL</b>                                                                                                     | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
|-----------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------------|----------------------|----------------------|
| (26) Welding current (not required for manual welding), including type and polarity                                   | —                          | —                          | X                          | X                    | —                    | X                          | —                    | —                    |
| (27) Accelerating voltage, beam current, beam focusing current, and filament type, size, and shape                    | —                          | —                          | —                          | —                    | —                    | —                          | X                    | —                    |
| (28) Beam power, beam distribution, and optical configuration                                                         | —                          | —                          | —                          | —                    | —                    | —                          | —                    | X                    |
| (29) Wire feed speed and voltage range, or control variables for synergic processes                                   | X                          | X                          | —                          | —                    | —                    | —                          | —                    | —                    |
| (30) Beam pulsing characteristics                                                                                     | —                          | —                          | —                          | —                    | —                    | —                          | O                    | O                    |
| (31) Voltage range (except not required for manual welding)                                                           | —                          | —                          | X                          | X                    | —                    | X                          | —                    | —                    |
| (32) Specification, classification, diameter, and electrode preparation/geometry of tungsten electrode                | —                          | —                          | X                          | X                    | —                    | —                          | —                    | —                    |
| (33) Metal Transfer mode (short circuit, globular, or spray)                                                          | X                          | X                          | —                          | —                    | —                    | —                          | —                    | —                    |
| (34) Pulsed welding power parameters                                                                                  | O                          | O                          | O                          | O                    | —                    | O                          | —                    | —                    |
| (35) Contact tube to work distance                                                                                    | X                          | X                          | —                          | —                    | —                    | —                          | —                    | —                    |
| <b>OTHER WELDING PROCESS VARIABLES</b>                                                                                | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (36) Working distance and angle (gun/optic to work piece)                                                             | —                          | —                          | —                          | —                    | —                    | —                          | X                    | X                    |
| (37) Welding process and whether manual, semiautomatic, mechanized or automatic                                       | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (38) For mechanized and automatic applications: number of electrodes and their spacing, if applicable                 | X                          | X                          | X                          | X                    | —                    | —                          | —                    | —                    |
| (39) Single or multipass weld                                                                                         | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (40) Method of initial and interpass cleaning                                                                         | X                          | X                          | X                          | X                    | X                    | X                          | X                    | X                    |
| (41) Peening, including method                                                                                        | O                          | O                          | O                          | O                    | —                    | O                          | —                    | —                    |
| (42) Conventional or keyhole technique                                                                                | —                          | —                          | X                          | X                    | —                    | —                          | X                    | X                    |
| (43) Standoff distance for mechanized and automatic welding                                                           | —                          | —                          | X                          | X                    | —                    | —                          | —                    | —                    |
| (44) Stringer or weave bead, including weave parameters                                                               | X                          | X                          | X                          | X                    | —                    | X                          | X                    | X                    |
| (45) Travel speed range for mechanized or automatic welding and manual applications requiring heat input calculations | X                          | X                          | X                          | X                    | —                    | —                          | X                    | X                    |
| (46) Fuel gas and flame type (oxidizing, neutral, carburizing)                                                        | —                          | —                          | —                          | —                    | X                    | —                          | —                    | —                    |
| (47) Beam oscillation pattern and parameters (e.g., length and width)                                                 | —                          | —                          | —                          | —                    | —                    | —                          | X                    | X                    |

**Legend:**

Fusion Welding Processes:

OFW—Oxyfuel welding

SMAW—Shielded metal arc welding

SAW—Submerged arc welding

GTAW—Gas tungsten arc welding

GMAW—Gas metal arc welding

FCAW—Flux cored arc welding

PAW—Plasma arc welding

EBW—Electron beam welding

LBW—Laser beam welding

**WPS Variables:**

X—Data that shall be included in a WPS.

O—Include this data when this variable gets used in the welding procedure.

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**Table 5.2**  
**Procedure Qualification Variables**

| <b>JOINT DESIGN</b>                                                                                                                                                                                                                                                                                                                                                                                                             | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------------|----------------------|----------------------|
| (1) For mechanized and automatic welds: a change in the groove weld type (V-groove, U-groove, square groove, etc.)                                                                                                                                                                                                                                                                                                              | Q                          | Q                          | Q                          | Q                    | —                    | —                          | Q                    | Q                    |
| (2) A change from a fillet to a groove weld                                                                                                                                                                                                                                                                                                                                                                                     | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (3) The addition or deletion of non-fusing metal or non-metallic backing or backing gas                                                                                                                                                                                                                                                                                                                                         | —                          | —                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (4) An increase in the fitup gap beyond that used in the qualification test                                                                                                                                                                                                                                                                                                                                                     | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (5) A change in the nominal part geometry adjacent to the joint                                                                                                                                                                                                                                                                                                                                                                 | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| <b>BASE METAL</b>                                                                                                                                                                                                                                                                                                                                                                                                               | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (6) A change from one base metal alloy to a different base metal alloy                                                                                                                                                                                                                                                                                                                                                          | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (7) A change in the base metal thickness beyond the range specified below:<br>A test weld with a base metal thickness of (t) shall qualify welds in base metals with a thickness range of 1/2t to 2t, except when the test weld base metal thickness is equal to or greater than 1 in [25 mm], the qualification range is 1/2t to unlimited.<br>Two test welds shall qualify welds with all intermediate base metal thicknesses | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | —                    | —                    |
| (8) A change in the nominal thickness (t) of the base metal                                                                                                                                                                                                                                                                                                                                                                     | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (9) For mechanized or automatic welds:<br>A change exceeding $\pm 10\%$ of base metal thickness (t) qualified                                                                                                                                                                                                                                                                                                                   | —                          | —                          | Q                          | Q                    | —                    | —                          | —                    | —                    |
| <b>FILLER METAL</b>                                                                                                                                                                                                                                                                                                                                                                                                             | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (10) A change in the filler metal alloy                                                                                                                                                                                                                                                                                                                                                                                         | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (11) A change in the chemical composition of the weld metal.<br>Each layer shall be considered independent of other layers                                                                                                                                                                                                                                                                                                      | C<br>H                     | C<br>H                     | C<br>H                     | C<br>H               | —<br>—               | C<br>H                     | —<br>—               | C<br>H               |
| (12) A change in the diameter of filler metal of $\pm 20\%$                                                                                                                                                                                                                                                                                                                                                                     | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (13) The addition or deletion of filler material                                                                                                                                                                                                                                                                                                                                                                                | —                          | —                          | Q                          | Q                    | —                    | —                          | Q                    | Q                    |
| (14) A decrease of the applied surfacing thickness below that qualified                                                                                                                                                                                                                                                                                                                                                         | C<br>H                     | C<br>H                     | C<br>H                     | C<br>H               | —<br>—               | C<br>H                     | —<br>—               | C<br>H               |
| (15) A change of filler metal/electrode nominal size/shape in the first layer                                                                                                                                                                                                                                                                                                                                                   | C<br>H                     | C<br>H                     | —<br>—                     | —<br>—               | —<br>—               | C<br>H                     | —<br>—               | —<br>—               |
| (16) The addition or deletions of supplementary filler metal (powder or wire)                                                                                                                                                                                                                                                                                                                                                   | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (17) A change exceeding $\pm 10\%$ of the amount of supplementary filler metal (powder or wire)                                                                                                                                                                                                                                                                                                                                 | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (18) A change from single to multiple supplementary filler metals or vice versa                                                                                                                                                                                                                                                                                                                                                 | C<br>H                     | C<br>H                     | C<br>H                     | C<br>H               | C<br>H               | C<br>H                     | —<br>—               | —<br>—               |
| <b>POSITION</b>                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (19) The addition of a welding position, except those positions other than flat also qualify for flat                                                                                                                                                                                                                                                                                                                           | C<br>H                     | C<br>H                     | C<br>H                     | C<br>H               | —<br>—               | C<br>H                     | —<br>—               | C<br>H               |

(Continued)

**Table 5.2 (Continued)  
Procedure Qualification Variables**

| <b>PREHEAT AND INTERPASS TEMPERATURE</b>                                                                                                                | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------------|----------------------|----------------------|
| (20) A decrease in preheat of more than 100°F [56°C]                                                                                                    | Q                          | Q                          | Q                          | Q                    | —                    | Q                          | Q                    | Q                    |
| (21) For all materials, an increase in the preheat or interpass temperature exceeding 100°F [56 °C]                                                     | Q                          | Q                          | Q                          | Q                    | —                    | Q                          | Q                    | Q                    |
| <b>POST WELD HEAT TREATMENT</b>                                                                                                                         | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (22) The addition or deletion of a post weld heat treatment (PWHT)                                                                                      | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (23) A decrease exceeding 20% of the aggregate time at temperature (i.e., soak time)                                                                    | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| <b>SHIELDING GAS</b>                                                                                                                                    | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (24) The addition or deletion of backing gas                                                                                                            | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (25) Addition or deletion of torch shielding gas                                                                                                        | Q                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (26) A change in the specified nominal composition of the shielding gas                                                                                 | Q                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (27) The addition or deletion of a purge chamber                                                                                                        | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (28) A change of shielding environment from vacuum to an inert gas or vice versa                                                                        | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (29) A change of vacuum pressure exceeding $\pm 1$ decade (order of magnitude, i.e., 10E-4 to 10E-5)                                                    | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (30) For titanium and zirconium base metals: a change in the nominal composition of the root shielding gas                                              | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (31) For titanium and zirconium base metals: a decrease exceeding 15% of the root shielding flow rate setting                                           | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (32) For titanium and zirconium base metals: a change in the nominal composition of the trailing gas                                                    | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (33) For titanium and zirconium base metals: a decrease exceeding 10% of the trailing gas flow rate setting                                             | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (34) For aluminum base metals: an increase exceeding 50%, or a decrease exceeding 20% of the shielding gas flow rate setting                            | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | Q                    |
| (35) A change exceeding $\pm 5\%$ of the flow rate setting change for any gas used in the process (the addition or deletion of gas exceeds a 5% change) | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| (36) A change in the orientation of the plasma plume removing gas jet relative to the workpiece (e.g., coaxial to transverse to the beam)               | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| (37) The addition or deletion of plasma plume removing gas jets                                                                                         | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| <b>ELECTRICAL CHARACTERISTICS</b>                                                                                                                       | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (38) A change from DC to AC and vice versa                                                                                                              | —                          | Q                          | Q                          | Q                    | —                    | Q                          | —                    | —                    |
| (39) A change from DCEN to DCEP and vice versa                                                                                                          | —                          | —                          | Q                          | —                    | —                    | Q                          | —                    | —                    |
| (40) A change in the mode of metal transfer from short circuiting to globular, spray, or vice versa; or the addition or removal of pulsing              | Q                          | Q                          | —                          | —                    | —                    | —                          | —                    | —                    |
| (41) A change of accelerating voltage exceeding $\pm 1\%$                                                                                               | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (42) A change of beam current amperage exceeding $\pm 1\%$                                                                                              | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (43) A change of beam focus current amperage exceeding $\pm 0.5\%$                                                                                      | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (44) A change exceeding $\pm 3\%$ in the average or CW laser power from that qualified                                                                  | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| (45) Any nominal change in beam (energy) pulse characteristics                                                                                          | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (46) A change in filament type, size, or shape                                                                                                          | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |

(Continued)



**Table 5.2 (Continued)  
Procedure Qualification Variables**

| <b>OTHER VARIABLES</b>                                                                                                                                              | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------|----------------------------|----------------------------|----------------------|----------------------|----------------------------|----------------------|----------------------|
| (47) A change in the welding process                                                                                                                                | Q                          | Q                          | Q                          | Q                    | Q                    | Q                          | Q                    | Q                    |
| (48) A change from multi-passes per side to a single pass per side                                                                                                  | Q                          | Q                          | Q                          | Q                    | —                    | Q                          | —                    | Q                    |
| (49) A change from a stringer bead to a weave bead for manual welding                                                                                               | C<br>H                     | C<br>H                     | C<br>H                     | C<br>H               | —<br>—               | C<br>H                     | —<br>—               | —<br>—               |
| (50) For heat-treatable aluminum metals: a change from a stringer to a weave bead, but not vice versa                                                               | —                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | —                    |
| (51) A change in the type of fuel gas                                                                                                                               | —                          | —                          | —                          | —                    | Q                    | —                          | —                    | —                    |
| (52) A change in the type of welding flame                                                                                                                          | —                          | —                          | —                          | —                    | Q                    | —                          | —                    | —                    |
| (53) A change in working distance exceeding $\pm 0.5\%$ or $\pm 0.040$ in [1.0 mm], whichever is less                                                               | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| (54) Any change in the optic configuration (e.g. final focus lens, fiber diameter)                                                                                  | —                          | —                          | —                          | —                    | —                    | —                          | —                    | Q                    |
| (55) A change in working distance exceeding $\pm 5\%$ (e.g., gun to workpiece)                                                                                      | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (56) A change in working angle exceeding $\pm 2^\circ$ (e.g., gun to workpiece)                                                                                     | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (57) A change exceeding $\pm 20\%$ in oscillation length or width from that qualified                                                                               | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (58) A change in oscillation pattern                                                                                                                                | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| (59) The addition of a cosmetic cover pass                                                                                                                          | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | —                    |
| (60) A change from single-sided welds to double-sided or vice versa                                                                                                 | —                          | —                          | —                          | —                    | —                    | —                          | Q                    | Q                    |
| <b>OTHER MECHANIZED AND AUTOMATED WELDING VARIABLES</b>                                                                                                             | <b>F<br/>C<br/>A<br/>W</b> | <b>G<br/>M<br/>A<br/>W</b> | <b>G<br/>T<br/>A<br/>W</b> | <b>P<br/>A<br/>W</b> | <b>O<br/>F<br/>W</b> | <b>S<br/>M<br/>A<br/>W</b> | <b>E<br/>B<br/>W</b> | <b>L<br/>B<br/>W</b> |
| (61) A change exceeding $\pm 10\%$ of the distance between the welding head and the workpiece                                                                       | Q                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | —                    |
| (62) A change of travel speed exceeding $\pm 5\%$ or $\pm 0.5$ in [13 mm] per minute, whichever is greater                                                          | —                          | —                          | Q                          | Q                    | —                    | —                          | Q                    | Q                    |
| (63) A change of travel speed exceeding $\pm 10\%$ or $\pm 1.0$ in [25 mm] per minute, whichever is greater                                                         | Q                          | Q                          | —                          | —                    | —                    | —                          | —                    | —                    |
| (64) A change in amperage exceeding $\pm 5\%$ or $\pm 5$ amps, whichever is greater                                                                                 | —                          | —                          | Q                          | Q                    | —                    | —                          | —                    | —                    |
| (65) A change in amperage exceeding $\pm 10\%$ or $\pm 10$ amps, whichever is greater                                                                               | Q                          | Q                          | —                          | —                    | —                    | —                          | —                    | —                    |
| (66) A change in arc voltage exceeding $\pm 5\%$ or $\pm 0.5$ volts, whichever is greater                                                                           | —                          | —                          | Q                          | Q                    | —                    | —                          | —                    | —                    |
| (67) A change exceeding $\pm 10\%$ wire feed speed                                                                                                                  | —                          | —                          | Q                          | Q                    | —                    | —                          | Q                    | Q                    |
| (68) A change in the number of electrodes in the same weld pool                                                                                                     | Q                          | Q                          | Q                          | —                    | —                    | —                          | —                    | —                    |
| (69) A change in the spacing of multiple electrodes, if applicable                                                                                                  | Q                          | Q                          | Q                          | —                    | —                    | —                          | —                    | —                    |
| (70) A change from a keyhole welding mode to a non-keyhole welding mode and vice versa: or the inclusion of both modes, unless each has been individually qualified | —                          | —                          | Q                          | Q                    | —                    | —                          | Q                    | Q                    |
| (71) A change exceeding $\pm 20\%$ in the oscillation variables                                                                                                     | Q                          | Q                          | Q                          | Q                    | —                    | —                          | —                    | —                    |

**Legend:**

Fusion Welding Processes:

OFW—Oxyfuel welding

SMAW—Shielded metal arc welding

SAW—Submerged arc welding

GTAW—Gas tungsten arc welding

GMAW—Gas metal arc welding

FCAW—Flux cored arc welding

PAW—Plasma arc welding

EBW—Electron beam welding

LBW—Laser beam welding

**Qualification Variables:**

Q—Qualification variable for all applications

C—Qualification variable for weld cladding applications

H—Qualification variable for hardfacing applications



**Table 5.3  
Procedure Qualification Test Requirements**

|                                            | Required | When specified by the Engineering Authority | Number of destructive test specimens |
|--------------------------------------------|----------|---------------------------------------------|--------------------------------------|
| <b>Groove Welds</b>                        |          |                                             |                                      |
| Visual Inspection <sup>a</sup>             | X        | —                                           | —                                    |
| Penetrant Testing <sup>a</sup>             | X        | —                                           | —                                    |
| Radiographic Testing <sup>a</sup>          | Class A  | Class B & C                                 | —                                    |
| Magnetic Particle Examination <sup>a</sup> | —        | X                                           | —                                    |
| Tension Test <sup>b</sup>                  | —        | X                                           | 2                                    |
| Bend Test <sup>d,e</sup>                   | —        | X                                           | 4                                    |
| Fracture Toughness Test <sup>b</sup>       | —        | X                                           | 1                                    |
| Metallographic Examination <sup>a</sup>    | —        | X                                           | 2 <sup>f</sup>                       |
| <b>Fillet Welds</b>                        |          |                                             |                                      |
| Visual Inspection <sup>a</sup>             | X        | —                                           | —                                    |
| Penetrant Testing <sup>a</sup>             | X        | —                                           | —                                    |
| Radiographic Testing <sup>a</sup>          | —        | X                                           | —                                    |
| Magnetic Particle Examination <sup>a</sup> | —        | X                                           | —                                    |
| Tension Test <sup>b</sup>                  | —        | X                                           | 4                                    |
| Bend-Break Test <sup>c,d</sup>             | —        | X                                           | 2                                    |
| Metallographic Examination <sup>a,c</sup>  | X        | —                                           | 2 <sup>f</sup>                       |
| <b>Weld Cladding</b>                       |          |                                             |                                      |
| Visual Inspection <sup>a</sup>             | X        | —                                           | —                                    |
| Penetrant Testing <sup>a</sup>             | X        | —                                           | —                                    |
| Radiographic Testing <sup>a</sup>          | —        | X                                           | —                                    |
| Magnetic Particle Examination <sup>a</sup> | —        | X                                           | —                                    |
| Chemical Analysis                          | —        | X                                           | 1                                    |

<sup>a</sup> Visual, NDE, and metallographic examinations shall be performed and evaluated in accordance with Clause 7.

<sup>b</sup> Acceptance criteria shall be determined by the Engineering Authority.

<sup>c</sup> When base metal thickness ( $t$ ) > 0.063 in [1.6 mm], bend-break testing of fillet welds is optional to metallographic examination. When base metal thickness ( $t$ ) ≤ 0.063 in [1.6 mm], break-bend testing is not permitted and metallographic examination is required.

<sup>d</sup> Bend test and bend-break test acceptance criteria shall be per Annex B.

<sup>e</sup> The use of bend testing in lieu of radiography shall be permitted only if the requirements of Annex B, Clause B 2 are met.

<sup>f</sup> Two non-adjacent specimens are required. One face of each specimen shall be evaluated.

### 5.3 Performance Qualification—General Requirements

**5.3.1 Welder, Welding Operator, and Tack Welder Functional Descriptions.** The definitions and functional descriptions for welder, welding operator, and tack welder are as defined in AWS A3.0.

**5.3.2 Vision Requirements.** Welders, welding operators, and tack welders shall meet the vision requirements of 5.3.2.1 and 5.3.2.2. The requirements for test administrators are given in 5.3.2.3.

#### 5.3.2.1 Visual Acuity Testing Requirements.

(1) Welders, welding operators, and tack welders shall demonstrate near vision acuity of 20/30 or better.

(2) Test method shall be one of the following:

a. Snellen

b. A tumbling E chart

c. An alternate vision test recognized to provide a measure of acuity equivalent to 20/30 near vision.

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(3) Visual acuity shall be demonstrated in at least one eye.

(4) Corrected or uncorrected vision may be used, however if corrected vision is used to pass the eye exam, it shall be recorded on the test report or qualification record.

(5) Minimum testing frequency is once every two years.

#### **5.3.2.2 Color Perception Requirements.**

(1) Color perception testing is only required when deemed necessary by the fabricator.

(2) When required, the fabricator will specify both the level of color perception and the recognized test method to assess if the color perception requirement is met.

#### **5.3.2.3 Test Administration Requirements.**

(1) All vision tests shall be administered by appropriately trained personnel designated by the fabricator or by qualified medical personnel.

(2) The test administrator is responsible for determining appropriate test parameters except for those specified in 5.3.2.1 and 5.3.2.2.

**5.3.3 Qualification Requirements.** To achieve qualified status, welders, welding operators, and tack welders shall demonstrate their skill by the following:

(1) Welders and welding operators shall produce acceptable test welds per the requirements of 5.4.6 using a WPS per 5.2.1, except welder or welding operator qualification may be performed concurrently with procedure qualification as noted in 5.2.2.

(2) Tack welders shall produce acceptable test welds per 5.4.8.

**5.3.3.1 Welder, Welding Operator, and Tack Welder Performance Qualification Variables.** A change to the performance qualification variables as identified in Table 5.4 shall require qualification.

**5.3.3.2 Concurrent Qualification of Tack Welders.** Welders qualified in accordance with the requirements of this specification are also qualified as tack welders within the limits of Table 5.5.

**5.3.3.3 Concurrent Qualification of Welding Operators.** Welders qualified in accordance with the requirements of this specification are also qualified as welding operators within the limits of Table 5.5, provided that the fabricator has documented evidence the welder has been trained to operate the automated or mechanized equipment.

**Table 5.4  
Performance Qualification Variables**

| <b>Qualification Variables</b>                                                                      | <b>Welder</b> | <b>Welding Operator</b> | <b>Tack Welder</b> |
|-----------------------------------------------------------------------------------------------------|---------------|-------------------------|--------------------|
| (1) Welding process (5.4.1)                                                                         | X             | X                       | X                  |
| (2) Base metal group (5.4.2)                                                                        | X             | X                       | X                  |
| (3) Type of weld, groove or fillet (Table 5.5)                                                      | X             | —                       | —                  |
| (4) A change from a double welded groove weld to a single welded groove weld                        | X             | —                       | —                  |
| (5) A change from a partial joint penetration (PJP) weld to a complete joint penetration weld (CJP) | X             | —                       | —                  |
| (6) Base metal thickness (5.4.3 and Table 5.5)                                                      | X             | X                       | —                  |
| (7) Base metal form, sheet or tube (5.4.5 and Table 5.5)                                            | X             | —                       | —                  |
| (8) Pipe or tube diameter (5.4.3 and Table 5.5)                                                     | X             | —                       | —                  |
| (9) Welding position (5.4.4 and Table 5.7)                                                          | X             | —                       | —                  |
| (10) Addition of filler metal                                                                       | X             | —                       | X                  |
| (11) Deletion of backing material                                                                   | X             | —                       | —                  |
| (12) A change from AC to DC and vice versa                                                          | X             | —                       | —                  |

### 5.3.4 Qualification/Certification Validity

**5.3.4.1 Initial Validity.** A welder, welding operator, or tack welder who has successfully completed performance qualification shall be certified for a period of two years.

**5.3.4.2 Extended Validity.** The fabricator may extend the initial certification period indefinitely provided an auditable record is maintained, from the date of initial qualification, documenting that the welder, welding operator, or tack welder has used the qualified process without periods of inactivity exceeding 6 months.

**5.3.4.3 Disqualification.** The certification of a welder, welding operator, or tack welder shall be revoked if any of the following conditions are met:

- (1) The initial certification period of 5.3.4.1 has been exceeded and was not extended in accordance with 5.3.4.2.
- (2) The welder, welding operator, or tack welder has failed to meet or maintain the visual acuity requirements in accordance with 5.3.2
- (3) There is a specific reason to question the ability of a welder, welding operator, or tack welder to meet the requirements for qualification.

**5.3.4.4 Reinstatement.** The individual disqualified may be retested for the qualification/certification sought. Reinstatement of certification shall require the individual to demonstrate ability and skills to the same or the current qualification test. The final authority for granting of certification or reinstatement of certification and retest frequency, training requirements, and overall evaluation of the individual's qualification in accordance with this document rests with the fabricator.

**5.3.5 Identification.** The fabricator shall assign a unique number or other identification to each welder, welding operator, or tack welder upon certification.

**5.3.6 Test Records.** The fabricator shall complete a performance qualification test record containing the qualification variables listed in Table 5.4 through Table 5.7, detailing the limits of the welder, welding operator, or tack welder qualification. These records shall be retained for the period of time specified in the contract or, if no retention time is specified, the period of record retention shall be for the duration of the qualification. (See Annex F for examples of forms.)

### 5.4 Performance Qualification—Detailed Requirements

**5.4.1 Welding Process.** For welders, welding operator, and tack welders, a test weld made with a given welding process qualifies only that welding process.

**5.4.2 Base Metals.** For welders, welding operators, and tack welders, a test weld made in a base metal included on one of the base metal groups of Table 5.6 qualifies only that base metal group, except as modified in 5.4.2.1.

**5.4.2.1 Group Qualification.** Qualification in a base metal group with a “B” designator also qualifies base metals with the same Roman numeral designator and an “A” designator. For example, a welder, welding operator, or tack welder qualified using Base Metal Group IIIB material for the test sample also qualifies for Base Metal Group IIIA.

**5.4.2.2 Dissimilar Materials Welds.** Welders, welding operators, and tack welders may also weld dissimilar alloy joints provided that they are qualified to weld each base metal alloy group represented in the joint.

#### 5.4.3 Qualification Ranges for Thickness and Tube Diameter.

- (1) Thickness and tube diameter qualification ranges shall be in accordance with Table 5.5.
- (2) Where a joint involves members with different thicknesses, qualification shall be based on the thinner member.
- (3) Tube fillet weld qualifications are based on tube thickness only, not mating sheet thickness.
- (4) These limits apply to both groove welds and fillet welds.

#### 5.4.4 Welding Position.

**5.4.4.1 Welders.** The welding positions qualified by a given test weld position are denoted in Table 5.7. The welding position designations are identified and illustrated in Figures 5.1, 5.2, 5.3, and 5.4.



**Table 5.5  
Thickness and Tube Diameter Limitations for Performance Qualification**

| Test Weldment |              |                     | Qualified Range        |                          | Tube OD                |
|---------------|--------------|---------------------|------------------------|--------------------------|------------------------|
| Metal Form    | Type of Weld | Thickness           | Thickness <sup>a</sup> |                          |                        |
|               |              |                     | Groove                 | Fillet                   |                        |
| Sheet         | Groove       | < 1 in [25.4 mm]    | 0.67t to 4t            | 0.67t to 4t <sup>b</sup> | ≥ 1 in [25.4 mm]       |
|               |              | ≥ 1 in [25.4 mm]    | 0.67t to unlimited     | 0.67t to unlimited       |                        |
|               | Fillet       | ≤ 0.063 in [1.6 mm] | —                      | 0.67t to 4t              |                        |
|               |              | > 0.063 in [1.6 mm] |                        | 0.67t to 4t <sup>b</sup> |                        |
| Tube          | Groove       | < 1 in [25.4 mm]    | 0.67t to 4t            | 0.67t to 4t <sup>b</sup> | Size tested and larger |
|               |              | ≥ 1 in [25.4 mm]    | 0.67t to unlimited     | 0.67t to unlimited       |                        |
|               | Fillet       | ≤ 0.063 in [1.6 mm] | —                      | 0.67t to 4t              |                        |
|               |              | > 0.063 in [1.6 mm] |                        | 0.67t to 4t <sup>b</sup> |                        |

<sup>a</sup> Two successful test welds may be used to qualify for all welds of intermediate thickness.

<sup>b</sup> Not qualified for material thicknesses 0.063 in [1.6 mm] or less.

**5.4.4.2 Welding Operators.** A test weld made in any position qualifies for all welding positions.

#### **5.4.5 Base Metal Form and Weld Type.**

**5.4.5.1 Welders.** The base metal forms and weld types qualified by a given test weld are denoted in Table 5.7. Welders qualified to perform groove welds are also qualified to perform plug and slot welding in the qualified position.

**5.4.5.2 Welding Operators.** A test weld of any base metal form of any weld type shall qualify for all base metal forms and all weld types.

**5.4.6 Test Welds.** Multiple test welds may be required to expand qualifications beyond the limits of Clause 5.3.3.1. Test welds shall be made in accordance with a WPS.

**5.4.6.1 Groove Test Weld in Sheet.** The test weld is a butt joint in sheet as described in Figure 5.5.

**5.4.6.2 Fillet Test Weld in Sheet.** The test weld is a T-joint in sheet as described in Figure 5.6.

**5.4.6.3 Groove Test Weld in Tube.** The test weld is a butt joint in tube as described in Figure 5.7.

**5.4.6.4 Fillet Test Weld in Tube.** The test weld is a tube to sheet joint as described in Figure 5.8.

**5.4.6.5 Special Applications.** When none of the test welds described above are applicable to a given production weld, a special welder, tack welder, or welding operator qualification limited to the specific application may be achieved with a test weld consisting of the given production weld or a test weld representative of the given production weld. The qualification is limited to the welding conditions of the test weld with regard to welding process, base metal composition, base metal thickness, welding position, base metal form, type of weld, and the other welding conditions of Table 5.4. The required inspection, examination, and acceptance criteria shall be consistent with 5.4.7 or with production part criteria.

#### **5.4.7 Inspection and Examination Requirements.**

**5.4.7.1 Inspection.** Test welds shall be accepted or rejected in accordance with the criteria for Class A welds in Table 7.1, except a 0.5 in [13 mm] section may be discarded at each end of the weld coupon in sheet. Fillet welds shall conform to Figures 5.11 through 5.14. Inspection methods shall be performed as follows:

- (1) External weld quality shall be evaluated using visual inspection in the as-welded condition.
- (2) Internal weld quality shall be evaluated using radiographic testing methods for groove welds and metallographic examination for fillet welds.



#### 5.4.7.2 Metallographic Examination.

(1) Blanks shall be removed in accordance with Figures 5.9 and 5.10 for fillet welds in sheet or tube. The four sections "M" to be evaluated (8 surfaces) shall be separated by blanks. If these sections cannot be separated by blanks, additional test weldments shall be used to create the required number of specimens to be evaluated.

(2) Metallographic examination shall be performed using magnification of 5X–100X.

(3) All required surfaces shall be evaluated to the relevant acceptance criteria per Table 7.1, Figures 5.11, 5.12, 5.13, and 5.14.

**5.4.7.3 Bend Testing.** Bend testing, in accordance with Annex B, may be substituted for radiographic examination of groove welds and metallographic examination of fillet welds.

**5.4.8 Tack Welding.** Tack welder performance qualification for tack welding operations may be accomplished by performing tack welding on a production part or by producing a test coupon using a WPS. The tack welds shall be visually examined as welded, requiring a nominal 7X to 10X magnification for cracks, inclusions, and surface contamination to the Class A visual acceptance criteria. Once this initial tack welding performance qualification is complete and documented, subsequent production tack welds need only be examined to the production welding requirements.

**Table 5.6  
Base Metal Groups for Qualification of Welders, Welding Operators, and Tack Welders<sup>a</sup>**

| Group | Materials                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IA    | Carbon and Alloy Steels: <ul style="list-style-type: none"> <li>Wrought Carbon Steel: (bar, sheet, plate, and shapes): A36, A53, A106, A131, A139, A283, A284, A441, A515, A516, A570, A572, A588, and the AISI carbon steels with a nominal carbon of 0.40 weight percent or less (1005–1040)</li> <li>Cast Carbon Steels: A216, A352, A389, A487</li> <li>Cast Low Alloy Steels: A217, A389, A 487</li> <li>Low Alloy Structural Steel<sup>b</sup>: A514, A517, A537, A633<sup>c</sup></li> <li>High Strength Boiler Plate and Forgings<sup>a</sup>: A302, A508, A533</li> <li>Ultra High Strength Steels: 18 Ni Maraging steels, 9 Ni–4 Co steels</li> </ul> |
| IB    | Heat Treatable Alloy Steels: <ul style="list-style-type: none"> <li>UNS G41300<sup>c</sup>, G41350, G41400, G43400, G86300, K22925, K44220, H11</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| IIA   | Stainless Steels: <ul style="list-style-type: none"> <li>UNS S20100, S20200, S21900, S30100, S30200, S30300, S30400, S30800, S30900, S31000, S31600</li> <li>UNS N08330, S31700, S32100, S34700, S34800, S63198, S631989, S21900</li> <li>UNS S40500, S40900, S42900, S43000, S43400, S43600, S43035, S44100, S44200, S44600</li> <li>UNS S40300, S41000, S41400, S41600, S42000, S42200, S43100, S44002, S44003, S44004</li> </ul>                                                                                                                                                                                                                             |
| IIB   | Precipitation Hardenable Stainless Steels: <ul style="list-style-type: none"> <li>UNS S13800, S15500, S15700, S17400, S17700<sup>c</sup>, S35000, S35500, S45000, S45500, S66286</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| IIIA  | Nickel and Nickel-Based Alloys: <ul style="list-style-type: none"> <li>UNS N02200, N02201</li> <li>UNS N04400</li> <li>UNS N06002, N06007, N06455, N06600, N06625<sup>c</sup>, N06975</li> <li>UNS N08020, N08320, N08800, N08810, N08825</li> <li>UNS N10001, N10002, N10003, N10276, N10665</li> </ul>                                                                                                                                                                                                                                                                                                                                                        |
| IIIB  | Precipitation Hardening Nickel and Nickel-Based Alloys: <ul style="list-style-type: none"> <li>UNS N05500, N06601, N07041, N07718<sup>c</sup>, N07750, N09706, N09901, N19903, N19907, N19909</li> <li>Rene 77, 80</li> <li>Udimet 700</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                               |
| IV    | Non Heat Treatable Aluminum Alloys: <ul style="list-style-type: none"> <li>UNS A91060, A91100, A93003, A93004, A95052, A95083, A95086<sup>c</sup>, A95154, A95254, A95454, A95456, A95652</li> </ul> Heat Treatable Aluminum Alloys: <ul style="list-style-type: none"> <li>UNS A03550, A03560, A03570, A92014, A92219, A96061<sup>c</sup>, A96063</li> </ul>                                                                                                                                                                                                                                                                                                   |

(Continued)

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**Table 5.6 (Continued)**  
**Base Metal Groups for Qualification of Welders, Welding Operators, and Tack Welders<sup>a</sup>**

| Group | Materials                                                                                                                                                                                          |
|-------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| V     | Magnesium Alloys:<br>• UNS M10100, M11311 <sup>c</sup> , M11610, M11800, M11910, M11920, M12330, M13210, M13310, M13312<br>• UNS M13320, M14141, M16620, M18220                                    |
| VI    | Titanium Alloys:<br>• UNS R50250, R50400, R50550<br>• UNS R54520, R54620, R54810, R56210, R56260, R56320, R56400 <sup>c</sup> , R56620, R58640<br>• Ti-6Al-2Sn-3Zr-2Cr-2Mo<br>• Ti-15V-3Cr-3Mo-3Sn |
| VII   | Cobalt-Based Alloys:<br>• UNS R30006, R30106, R30021, R30023, R30027, R30030, R30031<br>• UNS R30188 <sup>c</sup> , R30605, R30816                                                                 |
| VIII  | Alloys that do not conform to Groups I–VII: <sup>d</sup><br>• Refractory alloys (Cb, Mo, W)<br>• Reactive alloys (Zr)<br>• Magnet alloys<br>• Copper alloys                                        |

<sup>a</sup> These are sample alloys. Tradenames may be provided for some common alloys without a UNS number. These tradenames are provided for information only; without regard for trademark status.

<sup>b</sup> These materials shall be considered as a separate subgroup. Qualification with an alloy identified with this symbol will also qualify for welding materials in the basic group not identified by the symbol.

<sup>c</sup> Recommended alloy for qualification of this alloy group.

<sup>d</sup> Each alloy in this group requires separate qualification.

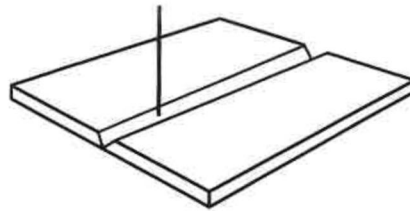
**Table 5.7**  
**Welder Qualification – Positions and Base Metal Forms Qualified by Sheet or Tube Tests**

| Qualification Test <sup>a</sup> |           |               | Positions Qualified <sup>b</sup> |         |                   |                      |
|---------------------------------|-----------|---------------|----------------------------------|---------|-------------------|----------------------|
|                                 |           |               | Sheet                            |         | Tube              |                      |
| Base Metal Form                 | Weld Type | Test Position | Groove                           | Fillet  | Groove            | Fillet               |
| Sheet                           | Groove    | 1G            | F                                | F, H    | F <sup>c</sup>    | F, H <sup>c</sup>    |
|                                 |           | 2G            | F, H                             | F, H    | F, H <sup>c</sup> | F, H <sup>c</sup>    |
|                                 |           | 3G            | F, V                             | F, H, V | F, V <sup>c</sup> | F, H, V <sup>c</sup> |
|                                 |           | 4G            | F, O                             | F, H, O | F, O <sup>c</sup> | F, H, O <sup>c</sup> |
|                                 | Fillet    | 1F            | —                                | F       | —                 | F <sup>c</sup>       |
|                                 |           | 2F            |                                  | F, H    |                   | F, H <sup>c</sup>    |
|                                 |           | 3F            |                                  | F, H, V |                   | F, H, V <sup>c</sup> |
|                                 |           | 4F            |                                  | F, H, O |                   | F, H, O <sup>c</sup> |
| Tube                            | Groove    | 1G            | F                                | F, H    | F                 | F, H                 |
|                                 |           | 2G            | F, H                             | F, H    | F, H              | F, H                 |
|                                 |           | 5G            | F, V, O                          | All     | F, V, O           | All                  |
|                                 |           | 6G            | All                              | All     | All               | All                  |
|                                 | Fillet    | 1F            | —                                | F       | —                 | F                    |
|                                 |           | 2F            |                                  | F, H    |                   | F, H                 |
|                                 |           | 4F            |                                  | F, H, O |                   | F, H, O              |
|                                 |           | 5F            |                                  | All     |                   | All                  |

<sup>a</sup> Use of heat sinks is optional.

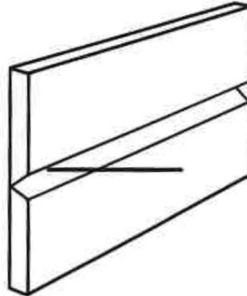
<sup>b</sup> Qualified positions for production welding are defined in AWS A3.0 as Flat (F), Horizontal (H), Vertical (V), Overhead (O). All = Flat, Horizontal, Vertical and Overhead.

<sup>c</sup> For qualified thickness and tube diameter range see Table 5.5.



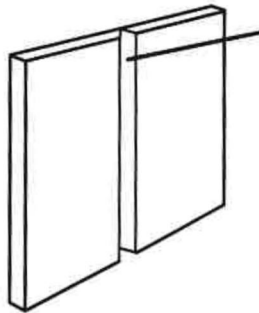
1G

**Flat position.** The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



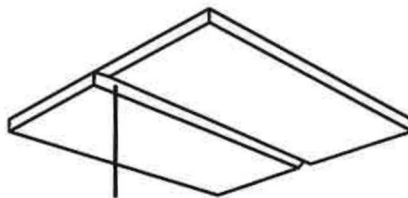
2G

**Horizontal position.** The position of welding in which the axis of the weld lies in an approximately horizontal plane and the face of the weld lies in an approximately vertical plane.



3G

**Vertical position.** The position of welding in which the axis of the weld is approximately vertical.

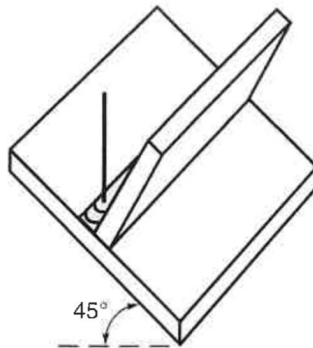


4G

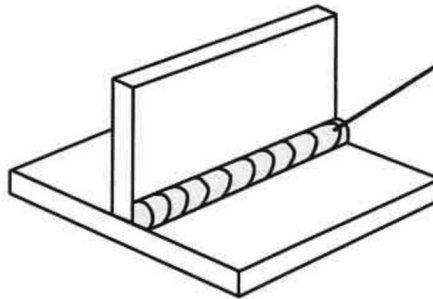
**Overhead position.** The position in which welding is performed from the underside of the joint.

**Figure 5.1—Groove Weld in Sheet: Positions 1G, 2G, 3G, and 4G**

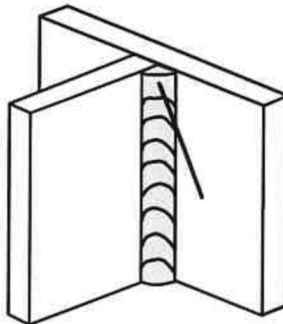
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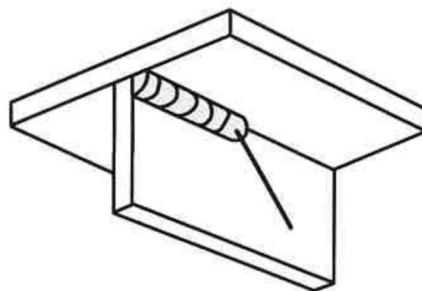
**Flat position.** The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal.



**Horizontal position.** The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface.



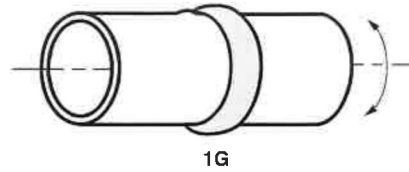
**Vertical position.** The position of welding in which the axis of the weld is approximately vertical.



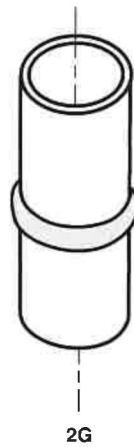
**Overhead position.** The position in which welding is performed from the underside of the joint.

**Figure 5.2—Fillet Weld in Sheet: Positions 1F, 2F, 3F, and 4F**

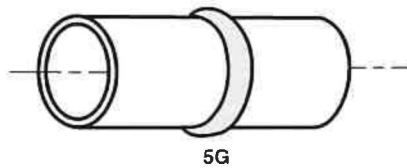




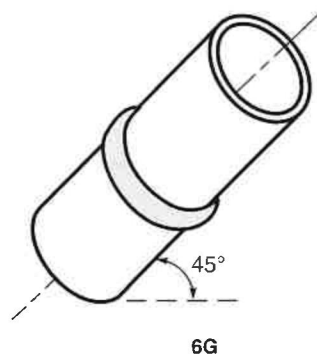
**Horizontal rolled position.** The position of a pipe joint in which the axis of the pipe is approximately horizontal, and welding is performed in the flat position by rotating the pipe.



**Vertical position.** The position of a pipe joint in which welding is performed in the horizontal position and the pipe is not rotated during welding.

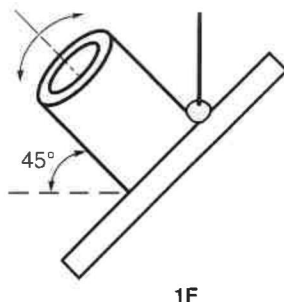


**Horizontal fixed position.** The position of a pipe joint in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

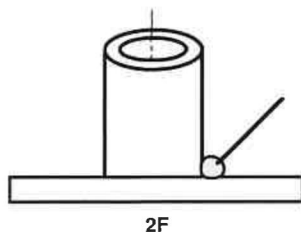


**Inclined position.** The position of a pipe joint in which the axis of the pipe is approximately at an angle of 45 degrees to the horizontal and the pipe is not rotated during welding.

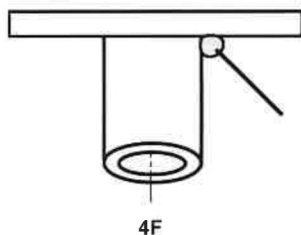
**Figure 5.3—Groove Weld in Tube: Positions 1G, 2G, 5G, and 6G**



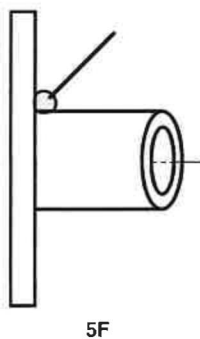
**Flat position.** The welding position used to weld from the upper side of the joint; the face of the weld is approximately horizontal and the pipe is rotated during welding.



**Horizontal position.** The position in which welding is performed on the upper side of an approximately horizontal surface and against an approximately vertical surface and the pipe is not rotated during welding.

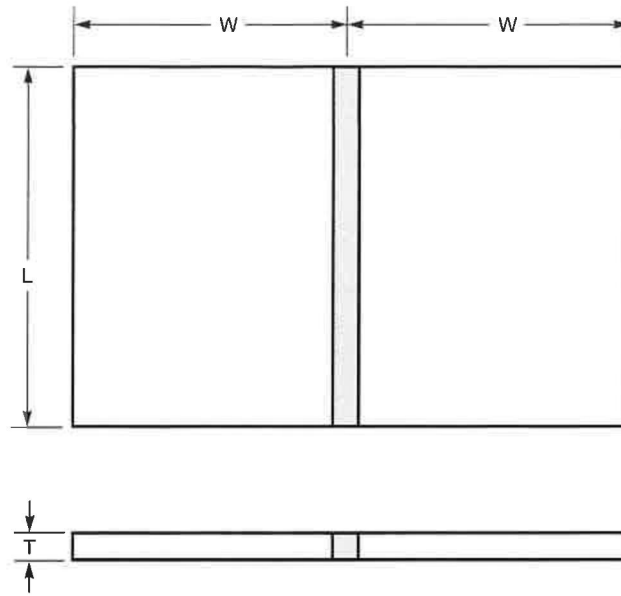


**Overhead position.** The position in which welding is performed from the underside of the joint and the pipe is not rotated during welding.



**Multiple Position.** The position in which the axis of the pipe is approximately horizontal and the pipe is not rotated during welding.

**Figure 5.4—Fillet Weld in Tube: Positions 1F, 2F, 4F, and 5F**



| Base Metal Thickness (in [mm]) |                | Minimum Dimensions (in [mm]) |
|--------------------------------|----------------|------------------------------|
| T                              | W <sup>a</sup> | L                            |
| ≤ 0.063 [1.6]                  | 2 [50]         | 5 [125]                      |
| > 0.063 [1.6]                  | 3 [75]         | 8 [200]                      |

<sup>a</sup> Suggested Dimension

**Figure 5.5—Groove Test Weld in Sheet**

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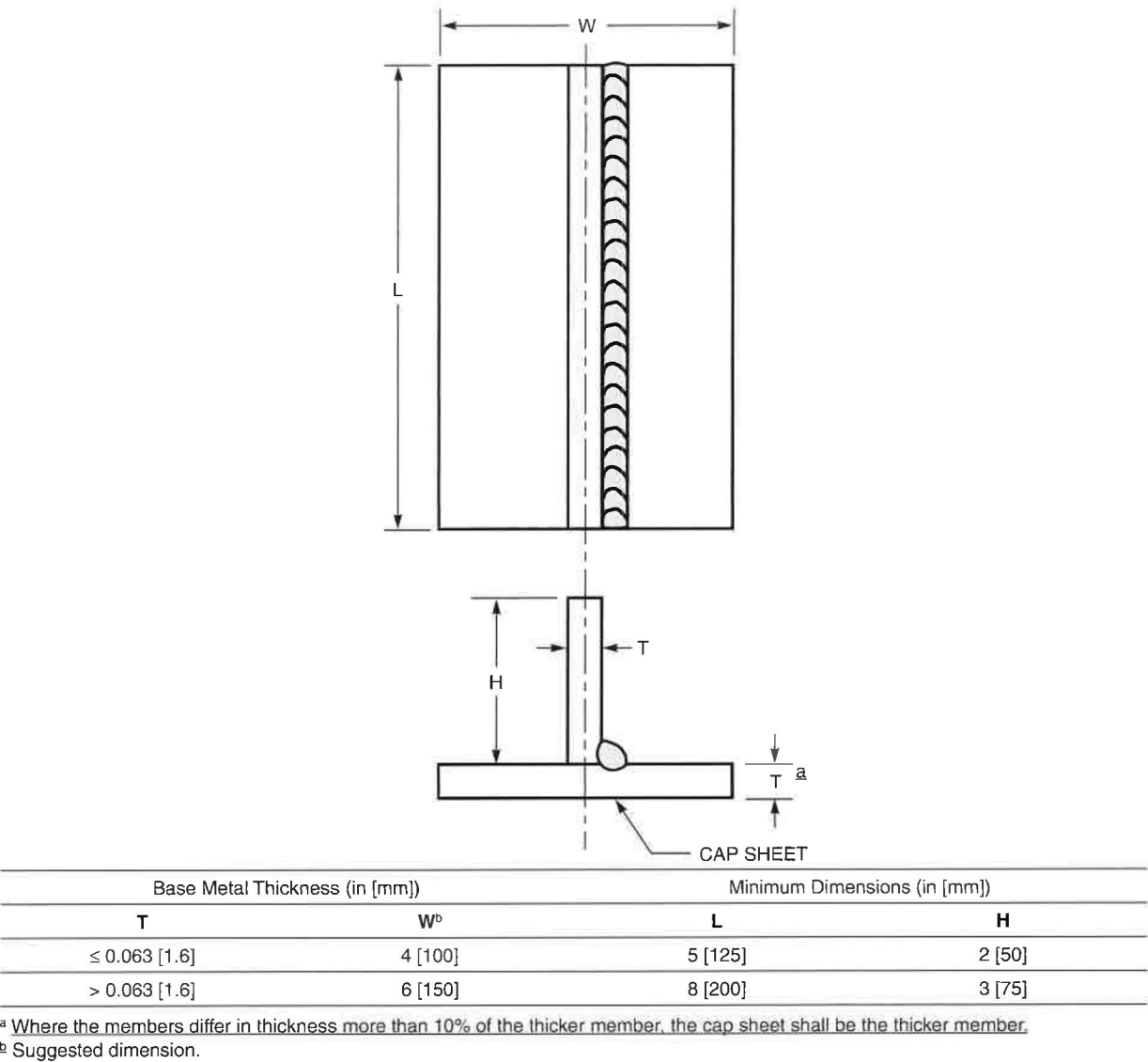


Figure 5.6—Fillet Test Weld in Sheet

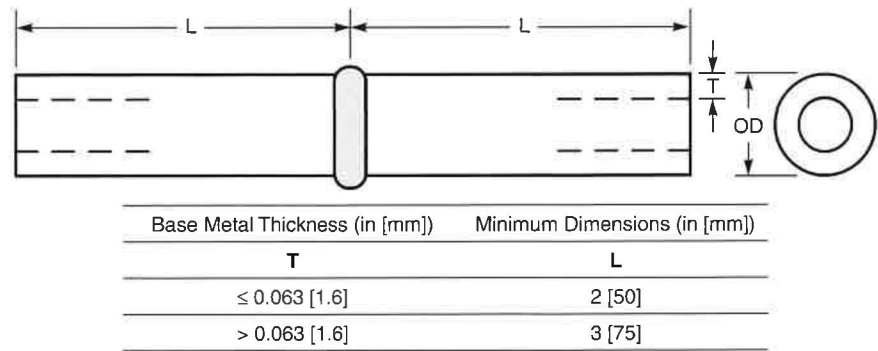
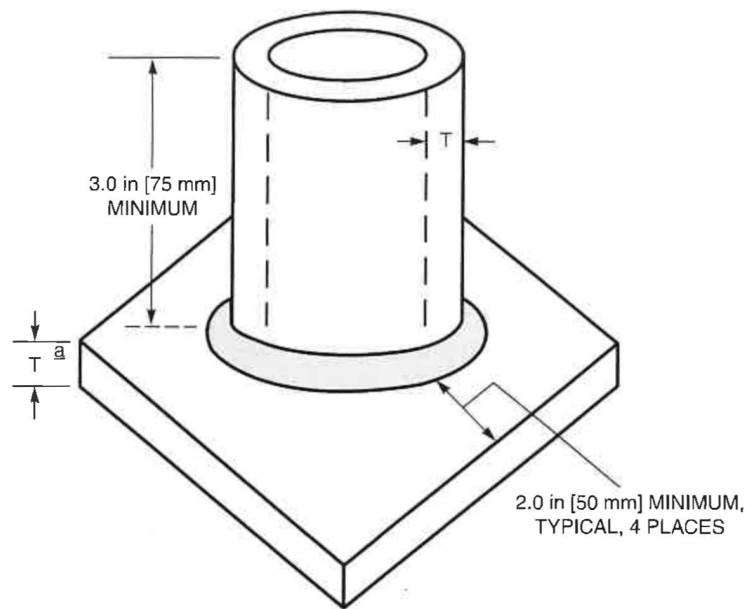


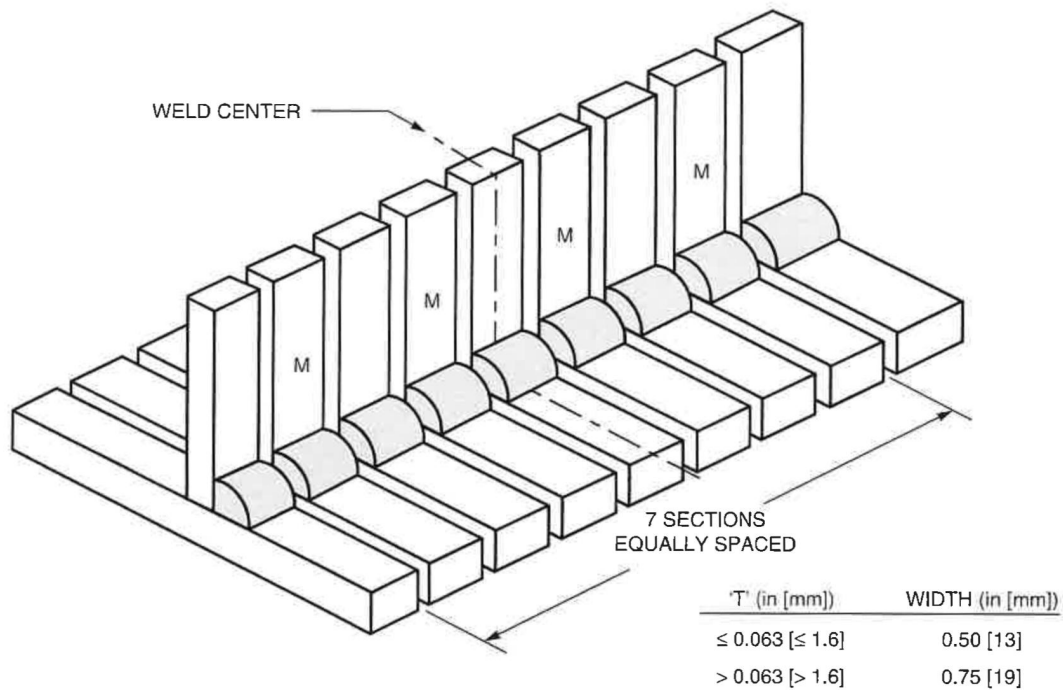
Figure 5.7—Groove Test Weld in Tube





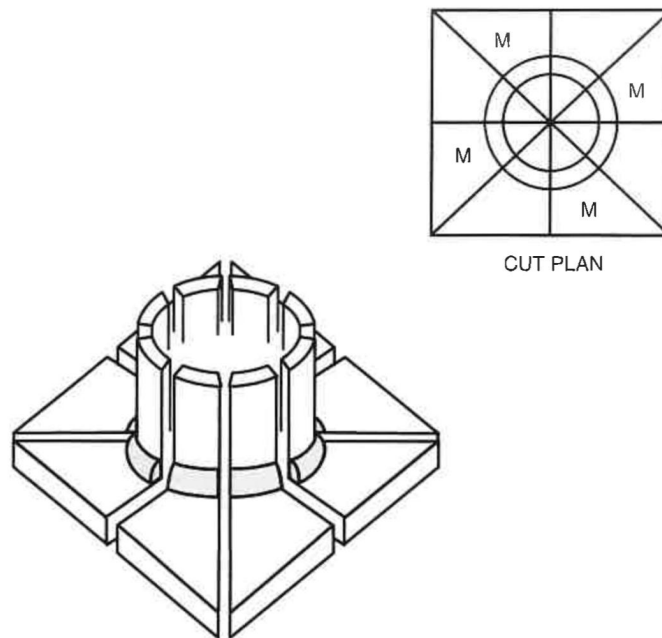
<sup>a</sup> Where the members differ in thickness equal to or more than 10% of the thicker member, the sheet shall be the thicker member.

**Figure 5.8—Fillet Test Weld in Tube**

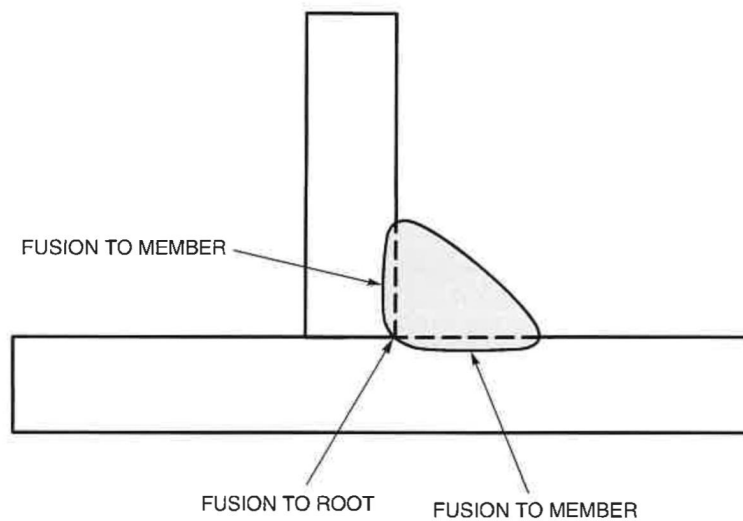


**Figure 5.9—Blank Locations for Metallographic (M) Specimens in Fillet-Welded Sheet**

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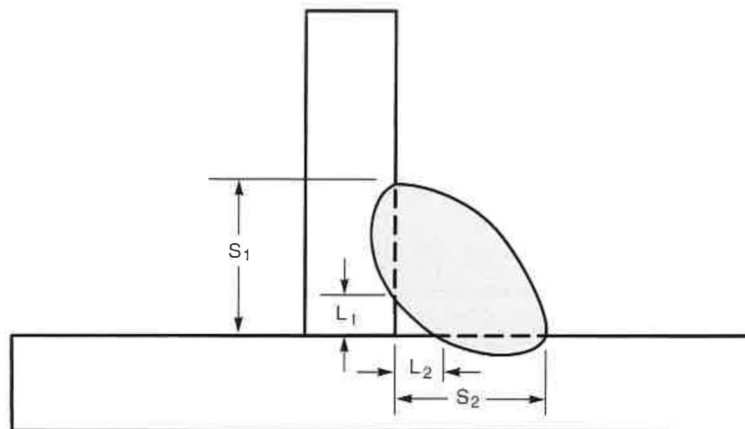
**Figure 5.10—Blank Locations for Metallographic (M) Specimens in Fillet-Welded Tube**



**Requirements:**

1. For all base metal thicknesses there shall be evidence of fusion into both members.
2. For joints with both members  $> 0.063$  in [1.6 mm] in thickness, there shall be evidence of fusion into the root of the joint.
3. For joints with either member  $\leq 0.063$  in [1.6 mm] in thickness, incomplete root fusion shall not exceed the requirements of Figure 5.12.

**Figure 5.11—Fusion in Fillet Welds**



Requirement: For joints with either member  $\leq 0.063$  in [1.6 mm] in thickness,  $L_1$  shall be  $\leq 0.1 \times S_1$  and  $L_2$  shall be  $\leq 0.1 \times S_2$

Legend:

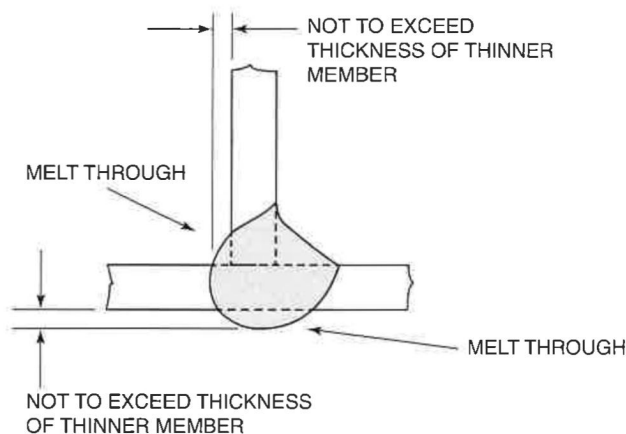
$L_1$  = Measured incomplete fusion at the root in vertical member

$L_2$  = Measured incomplete fusion at the root in horizontal member

$S_1$  = Measured leg size in vertical member

$S_2$  = Measured leg size in horizontal member

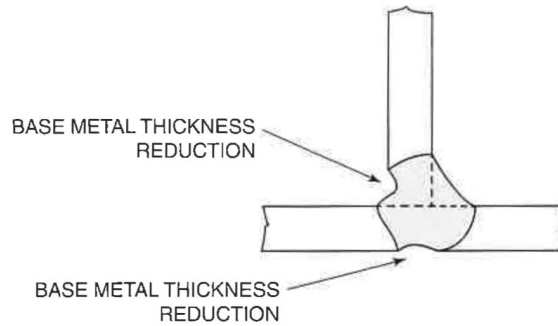
**Figure 5.12—Incomplete Fusion at the Root in Fillet Welds**



Requirements:

1. For joints with both members  $> 0.063$  in [1.6 mm] in thickness, melt through evident at any surface opposite to the weld face shall be unacceptable.
2. For joints with any member  $\leq 0.063$  in [1.6 mm] in thickness, melt through evident at either surface opposite to the weld face shall not exceed the thickness of the thinner member.

**Figure 5.13—Melt Through in Fillet Welds**



Requirement: For all base metal thicknesses, evidence of melting at any sheet or tube surface opposite the weld face resulting in base metal thickness reduction shall be unacceptable.

**Figure 5.14—Base Metal Thickness Reduction in Fillet Welds**

## 6. Fabrication

**6.1 Scope.** This clause establishes requirements for the fabrication of weldments.

### 6.2 Welding Consumables

**6.2.1 Identification (Bare Welding Wire and Welding Rods, Electrodes, Inserts, and Fluxes).** Consumables used in welding shall be identified in accordance with an established standard or specification or by a standard specified in the procurement specification. If the identification marking is destroyed or missing, the consumable shall not be used. When specified on the engineering drawing or a contract document, traceability of the consumables shall be maintained throughout the welding process.

#### 6.2.2 Storage and Use

**6.2.2.1 Filler Metals.** Welding filler materials shall be stored in a clean and dry environment. Filler metal types shall not be commingled during storage or use. Heating may be employed as necessary to prevent moisture accumulation. Low hydrogen SMAW and FCAW electrodes shall be handled and stored according to manufacturer's recommendations or according to AWS A5.1/A5.1M, A5.5/A5.5M, A5.20/A5.20M, or A5.29/A5.29M, as appropriate.

**6.2.2.2 Welding Fluxes.** Fluxes shall be labeled and segregated by type and/or by their particular application. To prevent moisture pickup, fluxes shall be stored in sealed containers or be kept in a suitably clean and dry environment. Clean unfused flux may be reused after reconditioning according to the manufacturer's recommendations.

#### 6.2.3 Gases

**6.2.3.1 Gas Procurement Specification.** Welding and shielding gases shall be procured to the requirements of Table 6.1 or to the requirements of AWS A5.32M/A5.32.

**6.2.3.2 Shielding Gas(es).** The chemical composition, volume percentage, and flow rate of each gas shall be as specified in the WPS.

*NOTE: Annex I provides recommendations for shielding gases to be used with various processes and material types.*

**6.3 Welding Equipment.** The welding equipment shall be capable of maintaining weld quality and consistency.

#### 6.3.1 Calibration

**6.3.1.1 Meters, Gauges, and Dials.** Except as specified in 6.3.1.2, meters, gauges, and dials installed on automatic, mechanized, or robotic welding apparatus shall be calibrated in accordance with an established procedure.

**6.3.1.2 Gas Flow Meters and Pressure Gauges.** Gas flow meters and pressure gauges do not require calibration.

**6.3.1.3 Calibration Procedures.** The fabricator shall establish and document applicable calibration procedures.



**Table 6.1  
Gas Requirements<sup>a</sup>**

| Gas            | Specification                             | Alternate Specification |
|----------------|-------------------------------------------|-------------------------|
| Argon          | MIL-DTL-18455                             | CGA G-11.1              |
| Helium         | BB-H-1168                                 | CGA G-9.1               |
| Oxygen         | BB-O-925A, Type I OR II                   | CGA G-4.3               |
| Nitrogen       | A-A-59503, Type I OR II, Class 1, Grade B | CGA G-10.1              |
| Hydrogen       | BB-H-886, Type I OR II                    | CGA G-5.3               |
| Acetylene      | BB-A-106, Grade B                         | CGA G-1.1               |
| Carbon Dioxide | BB-C-101, Grade B                         | CGA G-6.2               |

Gas Mixtures—The purity of the gases in the mixture shall be as specified for the individual gas listed above. Composition of the gas mixture shall be as specified by the Engineering Authority

<sup>a</sup> Refer to 6.2.3.1

**6.3.1.4 Calibration Period.** Required calibrations shall be performed at an interval of two (2) years or less. Required calibrations shall also be performed when meters, gauges, and dials have been affected by repairs made to automatic, mechanized, or robotic welding apparatus.

**6.4 Machine Welding Parameters.** Welding parameters shall be set within the limits specified in the WPS.

**6.4.1 Reproducibility Tests for Qualified Machine Welding Settings**

**6.4.1.1 Applicability of Requirements.** These requirements are applicable to automatic, mechanized, and robotic equipment only. The reproducibility test shall be performed according to 6.4.1.2 when either of the following is encountered:

- (1) The equipment fails to produce acceptable weld quality in accordance with the settings of a qualified WPS.
- (2) A major component of the equipment is either repaired or replaced (as determined by the fabricator).

**6.4.1.2 Test Requirements.** The reproducibility test shall be performed according to a written procedure. The written procedure shall establish welding parameters, test specimen configuration, and acceptance criteria for the welded test specimen(s).

**6.5 Preweld Cleaning and Other Preparation**

**6.5.1 Surface Cleaning.** All surfaces to be welded and surfaces that may affect quality of the resulting weld (e.g., welding filler materials and fixtures) shall be free from slag, surface oxides, scale, protective finishes, oils, grease, dirt, or any other contaminants. Chemical methods (e.g., alkaline cleaning, solvent wipe, or etching) or mechanical methods (e.g., wire brushing, scraping, abrasive blasting, or machining) shall be used before welding, as needed, to ensure compliance to these requirements.

**6.5.1.1 Prohibited Solvents.** Halogenated solvents, of which chlorinated solvents are a subset, or methyl alcohol shall not be used when cleaning titanium or titanium alloys.

**6.5.1.2 Cleaning Tools.** The fabricator shall manage the use of mechanical cleaning devices to prevent cross contamination between incompatible materials while adhering to the following:

- (1) Wire brushes.
  - (a) For carbon and low alloy steels, austenitic stainless steel or carbon steel wire brushes may be used.
  - (b) For all other materials, wire brushes shall be austenitic stainless steel.
- (2) Mechanical cleaning devices.
  - (a) For carbon and low alloys steels, titanium, magnesium, and aluminum, mechanical cleaning devices shall only be used on the respective material group in accordance with a documented segregation method.
  - (b) For nickel, stainless steel, or cobalt alloys, mechanical cleaning devices may be used on any material from the nickel, stainless steel, or cobalt alloy groups.

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(c) For Group VIII alloys, mechanical cleaning devices shall be identified by alloy type and used only on that alloy type.

**6.5.2 Contamination of Cleaned Surfaces.** Previously cleaned surfaces shall be protected from contamination. If contamination does occur, the surfaces shall be cleaned again by one of the methods specified in 6.5.1 before welding.

## 6.6 Preweld Joint Preparation and Fitup

**6.6.1 Joint Preparation.** The edge of each joint member shall be prepared as specified by the weld symbols on the engineering drawing.

*NOTE: Annex A provides guidelines for joint preparation.*

**6.6.2 Fitup.** Unless otherwise specified on the Engineering drawing or WPS, fitup tolerances shall be in accordance with Annex A.

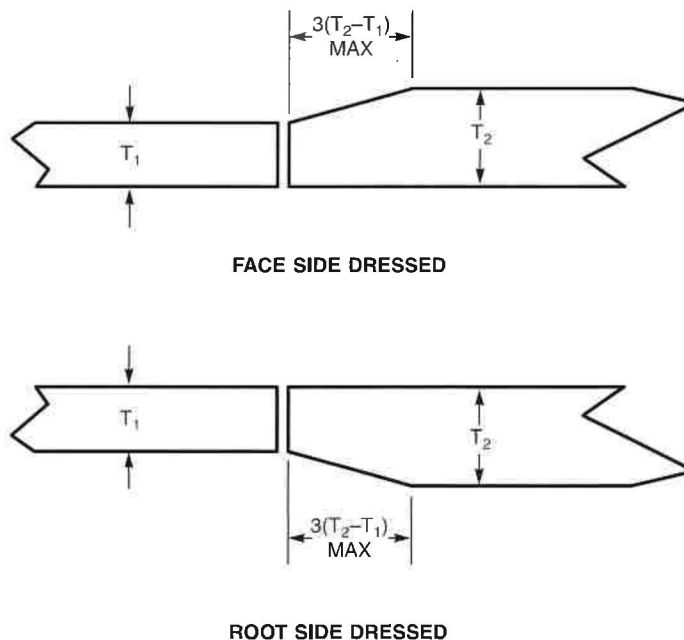
**6.6.3 Flange Joint Fitup.** Flange joint fitup shall be in accordance with the weld symbols on the engineering drawing.

*NOTE: Annex A provides guidelines for the flange joint fitup.*

### 6.6.4 Joint Members of Unequal Thickness

**6.6.4.1 Joint Member Preparation.** Joint members shall be prepared as shown in Figure 6.1 when the following conditions exist:

- (1) a full penetration weld is specified on the engineering drawing
- (2) both joint members exceed 0.125 in [3.2 mm] in thickness
- (3) the thickness ratio between joint members meets or exceeds: 1.5:1



Note: Refer to 6.6.4.1.

**Figure 6.1—Joint Preparation in Joint Members of Unequal Thickness**

**6.7 Preheating and Interpass Temperature Control.** Preheating and interpass temperature shall be established for materials susceptible to cracking during or after welding. Temperatures which are found to reduce the tendency to form cracks shall be included in the WPSs and employed when welding production hardware.

*NOTE: Table 6.2 provides recommended preheat and interpass temperatures for some materials.*

**6.8 Tack Welds.** Filler material used for tack welds shall be the same as that used for subsequent welding unless otherwise specified on the engineering drawing or listed in the qualified and Engineering Authority-approved WPS. Tack welds shall be consumed during subsequent welding unless removed in other processing. The requirements of 6.6 and 6.7 will be considered during the tack welding operations.

**6.9 Weld Start and Run-Off Tabs.** Weld start and run-off tabs, when used, shall be composed of the same alloy as the joint members. They shall be welded with the same filler material as that filler material specified on the engineering drawing or the qualified and Engineering Authority-approved WPS.

**6.10 Weld Shielding for GTAW, GMAW, and PAW.** The weld and the heat-affected zones (including deposited weld metal behind the weld pool in reactive materials, such as titanium and its alloys) shall be protected from oxidation during welding. The shielding method shall be included in the WPS and shall be used during the welding of the reactive materials, such as titanium and its alloys.

**6.11 Tungsten Electrodes.** Tungsten electrodes, when required, shall be in accordance with AWS A5.12M/A5.12 (ISO 6848 MOD).

**6.12 Filler Materials.** Any welding process requiring filler material shall only be performed using the filler material specified on the WPS as specified by the engineering drawing. When a filler material is not specified, welding shall not be performed until the Engineering Authority provides pertinent filler material information. This requirement is not applicable to autogenous welds (welds made without filler material).

*NOTE: Reference Annex I for common filler metal guidelines.*

**6.13 Interpass Cleaning.** When interpass cleaning is performed, mechanical methods specified in 6.5.1 shall be used.

**6.13.1 Interpass Cleaning of Titanium and Titanium Alloys.** Interpass cleaning of titanium or titanium alloy parts shall only be performed following visual inspection and acceptance of the surface discoloration to the requirements of Table 7.1.

**6.14 Welding and Weldments.** The welding of joint members and the resulting weldment shall comply with the requirements specified in the following subclauses:

**6.14.1 Arc Strike.** The welding arc shall not be struck on any portion of the base metal away from the surfaces to be joined. When indication of an arc strike or an arc burn is present in an area other than the designated joint or weld zone, the weldment shall be rejected as required in Clause 7.

**6.14.2 In-Process Correction.** Any correction of a weld made by the welder or welding operator before submitting the weldment for acceptance inspection in accordance with Clause 7 is an in-process correction. The correction shall occur before subjecting the weld to any heat treat operations. Before initiating in-process correction, surfaces to be welded shall be cleaned to remove oxide and other contaminants in accordance with 6.5.1.

**Table 6.2  
Preheat and Interpass Temperatures<sup>a</sup>**

| Base Metal Being Welded                                                     | Recommended Preheat and/or Interpass Temperature |
|-----------------------------------------------------------------------------|--------------------------------------------------|
| Carbon and Alloy steel with carbon equivalent 0.35% or greater <sup>b</sup> | 600°F [315°C] Maximum <sup>b,c</sup>             |
| Stainless Steel – Austenitic                                                | 350°F [175°C] Maximum                            |
| Stainless Steel – Martensitic                                               | 400°F to 600°F [205°C to 315°C]                  |
| Magnesium alloys in condition F                                             | 450°F to 500°F [232°C to 260°C]                  |
| Magnesium alloys in condition T                                             | 250°F to 300°F [121°C to 149°C]                  |

<sup>a</sup> Refer to 6.7

<sup>b</sup> The method provided in AWS D1.1/D1.1M may be used to determine carbon equivalent, preheat temperature, and interpass temperature.

<sup>c</sup> This is a maximum temperature. Depending upon part configuration and weld environment, the user should establish a temperature equal to or less than this temperature that is suitable for use in production welding.



**6.14.2.1 Welds Made Using Filler Material.** For welds made using filler material the following applies:

(1) An undercut, underfill, or crater (without crack) shall be considered as a surface depression and corrected by depositing filler material (the same as used in making the original weld) that blends into the weld and the base metal.

(2) An overlap, weld reinforcement, or other protruding indication may be removed by a metal removal method that will not degrade the material's properties. Corrections shall be performed in such a manner that the weld size and base metal thickness will remain within drawing tolerances. The corrected weld bead shall comply with Clause 6.14.3.

**6.14.2.2 Mechanized, Automatic, or Autogenous Welds.** In-process corrections using nonmanual or autogenous welds may be performed providing the same process and parameters are used as used in original weld. Any other process or parameters are only allowed when the engineering drawing or contract document allows such correction.

**6.14.2.3 Allowed Number of In-Process Correction Attempts.** One in-process correction attempt is allowed in each individual flaw location. When the in-process correction requires more than one attempt at the same flaw location, the combination of corrections shall be qualified as the original weld, with WPS and supporting PQR, or approved by the appropriate Material Review Board.

**6.14.2.4 Documentation of In-Process Correction.** The in-process correction history shall be documented when required by the Engineering Authority. The method and extent of documentation shall be agreed upon by the Engineering Authority and the fabricator.

**6.14.3 Removal of Weld Reinforcement.** Weld reinforcement removal shall be accomplished using methods that do not reduce the thickness of the base metal. Weld reinforcement shall only be removed for one or more of the following reasons:

(1) When specified by the engineering drawing notes or weld symbol. (The removal shall not exceed limits specified on the engineering drawing or any other contractual document.)

(2) When necessary to aid in the interpretation of nondestructive inspection indications. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.

(3) When fit or function of the final assembly dictate material removal. Remaining reinforcement shall be visually evident above the surface plane of the adjacent joint member and extend throughout the weld bead width. The weld toe area shall comply with the requirements of Clause 7.

**6.15 Postweld Cleaning.** The completed weldment shall be free of spatter, flux, scale, slag, or other foreign matter. Removal of such material during the postweld cleaning operation shall not reduce the weld bead size or base metal thickness below engineering drawing tolerances.

**6.15.1 Postweld Cleaning of Welded Titanium or Titanium Alloy Parts.** Postweld cleaning of welded titanium or titanium alloy parts shall only be performed after completion of a visual inspection and acceptance of the surface discoloration in accordance with Table 7.1.

**6.16 Postweld Processing.** Stress relieving, heat treatment, or any other postweld processing of the weldment shall be as specified on the engineering drawing or the qualified WPS.

## **6.17 Weld Identification Requirements**

**6.17.1 Interim Identification.** Interim marking of the weldment or the applicable shop planning paperworks shall be made by each welder or welding operator. Alternative tracking methods may be used with approval from the Engineering Authority. The interim identification shall remain next to or with the weld through final inspection. Marking methods and materials used shall neither be detrimental to the base metal nor interfere with subsequent operations.

**6.17.2 Final Identification.** Each welded assembly or the documentation accompanying each welded assembly shall be marked as follows:

- (1) date of welding
- (2) welder's signature or individually assigned stamp or code
- (3) date of weld inspection
- (4) weld inspector's signature or individually assigned stamp or code



**6.18 Acceptance Inspection.** The completed weldment shall be submitted to the fabricator's quality assurance organization or its designee for an acceptance inspection. The acceptance inspection shall be performed in accordance with Clause 7.

**6.19 Rework.** Rework is any corrective action made to a weldment in the as-welded condition following visual or NDT inspection. The corrective action shall bring the weldment into full conformance with the engineering drawing and the requirements of this specification. Except as specified herein, rework shall be made using the same process used to make the original weld and every requirement of 6.14 applies for rework.

**6.19.1 Rework by GTAW.** The manual GTAW process may be used at the fabricator's discretion to correct weld discontinuities for all welding processes. The WPS used to perform the rework shall be qualified using both welding processes and meet the requirements of the original weld.

**6.19.2 Allowed Number of Rework Attempts.** The allowed number of rework attempts shall be as established in the WPS and supporting PQR.

**6.19.3 Root Area Rework.** A weld with inadequate penetration or incomplete fusion at the root may be corrected by welding from the root side. Proper preparation of the root side shall be performed to obtain sound metal prior to welding. The prepared surface shall smoothly transition and fair into all surfaces to be fused in the rework.

**6.19.4 Documentation of Rework.** All operations involved in rework shall be documented using a method approved by the Engineering Authority.

**6.19.5 Inspection of the Rework.** The reworked weldment shall be submitted for an acceptance inspection in accordance with Clause 7.

**6.20 Repair.** Repair is any corrective action on a part directed by the Customer or its designee (Material Review Board). Repairs may be made to repair defects in welds.

**6.20.1 Repair Instructions.** The Engineering Authority or its designee shall provide detailed instructions for the repair that include but are not limited to:

- (1) allowed number of weld repair attempts
- (2) required documentation
- (3) details for each operation (including inspection methods, acceptance criteria, and post weld treatments) involved in the repair

## 7. Inspection

### 7.1 Qualification of Inspection Personnel

**7.1.1 Qualification of NDE Personnel.** Nondestructive examination personnel shall be qualified in accordance with NAS410 or another NDE standard that is satisfactory to the Engineering Authority. When the contract, purchase order, or engineering drawing specifies the use of an examination method not presently incorporated in NAS 410, the fabricator shall be responsible for developing and submitting to the Engineering Authority the training program, written practice, examination, and practical demonstrations equivalent to the requirements of NAS 410 or other standards. These shall establish the capability of the personnel performing the required examination.

**7.1.2 Visual Weld Inspectors.** All personnel performing visual weld inspections shall be certified by one of the following:

- (1) AWS QC1
- (2) a certification program approved by the Engineering Authority
- (3) a certification program approved by the fabricator's quality organization management, that is based on experience, training, and testing criteria cited in AWS B5.2

**7.1.3 Vision Requirements.** Vision requirements for visual weld inspectors shall meet the requirements of 7.1.3.1 and 7.1.3.2. The requirements for test administrators are given in 7.1.3.3.

**7.1.3.1 Vision Acuity Requirements.**

- (1) The visual weld inspector shall demonstrate near vision acuity of 20/30 or better.
- (2) Test method shall be one of the following:
  - a. Snellen
  - b. A tumbling E chart
  - c. An alternate vision test recognized to provide a measure of acuity equivalent to 20/30 near vision
- (3) Visual acuity shall be demonstrated in at least one eye.
- (4) Corrected or uncorrected vision may be used, however if corrected vision is used to pass the eye exam, it shall be recorded on the test report or qualification record.
- (5) Minimum testing frequency is once every two years.

**7.1.3.2 Color Perception Requirements.**

- (1) The fabricator may require a level of color perception for the visual weld inspector.
- (2) When required the fabricator will specify both the level of color perception and the recognized test method to assess if the color perception requirement is met.

**7.1.3.3 Test Administration Requirements.**

- (1) All vision tests shall be administered by appropriately trained personnel designated by the fabricator or by qualified medical personnel.
- (2) The test administrator is responsible for determining appropriate test parameters except for those specified in 7.1.3.1 and 7.1.3.2.

**7.2 Visual Weld Inspection.** All welds shall be visually inspected for conformance to drawing requirements by personnel qualified in accordance with 7.1.2 and 7.1.3.

**7.3 Nondestructive Examination.** NDE inspections are required to be performed using written procedures approved by an NDE Level III inspector certified in the appropriate inspection method.

**7.3.1 Penetrant Testing (PT).** All nonferromagnetic Class A and Class B welds shall be penetrant tested. Ferromagnetic Class A and Class B welds shall be penetrant tested when specified on the drawing or in the contract. Class C nonferromagnetic and ferromagnetic welds shall be penetrant tested when specified on the drawing or in the contract. Penetrant testing shall be conducted in accordance with ASTM E1417 using an approved Type I penetrant system, any method, sensitivity level 2 or better, and with or without developer. Equivalent processes may be used with engineering authority approval.

**7.3.2 Magnetic Particle Testing (MT).** All ferromagnetic Class A and Class B welds shall be magnetic particle tested using a wet fluorescent continuous method in accordance with ASTM E1444 or equivalent, unless penetrant testing is required by the drawing or contract. Class C ferromagnetic welds shall be magnetic particle tested when specified on the drawing or in the contract.

**7.3.3 Radiographic Testing (RT).** All Class A groove welds shall be radiographically tested in accordance with ASTM E1742, or a nonfilm technique permitted by ASTM E1742, unless ultrasonic testing is required by the drawing or in the contract. When radiographic testing of fillet welds or partial penetration groove welds is required, the Engineering Authority shall determine the acceptance criteria of the root. Class B and Class C welds shall be radiographically tested when specified on the drawing or in the contract.

**7.3.4 Ultrasonic Testing (UT).** Ultrasonic testing may be used in lieu of radiographic testing when specified by the drawing, in the contract, or by the Engineering Authority. Ultrasonic testing shall be in accordance with ASTM E164 or equivalent. When immersion or phased array ultrasonic testing is indicated, an approved standard shall be determined by the Engineering Authority.

**7.3.5 Proof Testing (PRT).** Proof testing may be used in conjunction with or in lieu of inspection methods listed in 7.3.1, 7.3.2, 7.3.3, and 7.3.4 when required by the drawing, in the contract, or when directed by the Engineering Authority (see Annex E—Commentary).

**7.3.6 Other Nondestructive Tests.** Nondestructive tests, procedures, techniques, equipment, or materials (e.g., Acoustic Emission, Electromagnetic or Eddy Current, Leak, Neutron Radiographic, etc.) not specifically addressed in this document may be used in conjunction with those stated on drawing or in the contract. When one or more of these inspection methods are indicated, an approved reference standard shall be determined by the Engineering Authority.

## 7.4 Acceptance Criteria

### 7.4.1 General Criteria.

- (1) The dimension of any discontinuity shall be defined by its largest dimension.
- (2) When not specified in Table 7.1, the following spacing requirements apply: two or more discontinuities shall be treated as one when the spacing between them is less than the dimension of the larger discontinuity.
- (3) Discontinuities that will be removed in subsequent machining shall not be cause for rejection.
- (4) Any weldment with unacceptable discontinuities which has gone through a subsequent manufacturing operation that affects the metallurgical characteristics (other than hydrogen embrittlement relief) or that cannot be reworked without affecting final metallurgical or surface characteristics, shall be rejected.
- (5) Removal of unacceptable weld metal is allowed provided that the minimum weld size is met. Incidental removal of base metal during discontinuity removal is acceptable provided minimum thickness requirements and any other engineering requirement (e.g., surface roughness) are met.

**7.4.1.1 Inspection with Magnification.** When performing visual inspection to determine acceptance of welded product, welds shall be inspected at magnifications from 1X to 10X. Discontinuities not detectable in this range shall not be cause for rejection. When measurements are taken at magnification over 10X (see 5.4.7.2), the rounding method of ASTM E29 shall be applied to all measured values in determining acceptance or rejection to the applicable requirements and associated significant digits within the requirement.

**7.4.2 Acceptable Welds.** Welds shall be acceptable if they meet the requirements of 7.4.1 and Table 7.1. The thickness (t) shall be considered the minimum weld joint thickness measured at the discontinuity, if the thickness cannot be measured, use the thinnest nominal thickness of the joint members. Welds not meeting these requirements shall be rejected. Rejected welds may be reworked in accordance with 6.19 or repaired in accordance with 6.20.

**7.4.2.1 Mismatch.** Unless otherwise specified on the engineering drawing or in any other contractual document, the maximum mismatch between joint members after welding shall meet the requirements of Figure 7.2.

**7.4.2.2 Angular Distortion or Peaking.** Unless otherwise specified on the engineering drawing or in any other contractual document, the angular distortion or peaking present upon completion of welding shall be within five degrees of the angle shown on the engineering drawing.



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**Table 7.1  
Acceptance Criteria (in [mm])**

| Discontinuity                                               | Class A                                                  | Class B                                                  | Class C                                                  |
|-------------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|----------------------------------------------------------|
| <b>Cracks</b>                                               | Not Allowed                                              | Not Allowed                                              | Not Allowed                                              |
| <b>Overlap (Cold Lap)</b>                                   | Not Allowed                                              | Not Allowed                                              | Not Allowed                                              |
| <b>Incomplete Fusion</b>                                    | Not Allowed                                              | Not Allowed                                              | Not Allowed                                              |
| <b>Incomplete Penetration<sup>a</sup></b>                   | Not Allowed                                              | Not Allowed                                              | Not Allowed                                              |
| <b>Porosity—Surface</b>                                     |                                                          |                                                          |                                                          |
| Individual size maximum                                     | 0.25 T or 0.030 [0.76],<br>whichever is less             | 0.33 T or 0.060 [1.5],<br>whichever is less              | 0.50 T or 0.090 [2.3],<br>whichever is less              |
| Spacing minimum <sup>b, c</sup>                             | 8 times the size of the larger<br>adjacent discontinuity | 4 times the size of the larger<br>adjacent discontinuity | 2 times the size of the larger<br>adjacent discontinuity |
| Accumulated length in any 3 in [75 mm]<br>of weld maximum   | 1 T or 0.12 [3.1], whichever is less                     | 1.33 T or 0.24 [6.1],<br>whichever is less               | 2 T or 0.36 [9.1],<br>whichever is less                  |
| <b>Porosity—Subsurface</b>                                  |                                                          |                                                          |                                                          |
| Individual size maximum                                     | 0.33 T or 0.060 [1.5],<br>whichever is less              | 0.50 T or 0.090 [2.3],<br>whichever is less              | Not applicable                                           |
| Spacing minimum <sup>b, c</sup>                             | 4 times the size of the larger<br>adjacent discontinuity | 2 times the size of the larger<br>adjacent discontinuity | Not applicable                                           |
| Accumulated length in any 3 in [75 mm]<br>of weld maximum   | 1.33 T or 0.24 [6.1],<br>whichever is less               | 2 T or 0.36 [9.1],<br>whichever is less                  | Not applicable                                           |
| <b>Inclusions</b>                                           |                                                          |                                                          |                                                          |
| Individual size maximum                                     | 0.33 T or 0.060 [1.5],<br>whichever is less              | 0.50 T or 0.090 [2.3],<br>whichever is less              | Not applicable                                           |
| Spacing minimum <sup>b, c</sup>                             | 4 times the size of the larger<br>adjacent discontinuity | 2 times the size of the larger<br>adjacent discontinuity | Not applicable                                           |
| Accumulated length in any 3 in [75mm]<br>of weld—maximum    | 1.33 T or 0.24 [6.1],<br>whichever is less               | 2 T or 0.36 [9.1],<br>whichever is less                  | Not applicable                                           |
| <b>Undercut<sup>a</sup></b>                                 |                                                          |                                                          |                                                          |
| For the full length of weld maximum<br>depth                | 0.002 [0.05]                                             | 0.015 T or 0.002 [0.05],<br>whichever is greater         | 0.025 T or 0.002 [0.05],<br>whichever is greater         |
| Individual discontinuity, maximum depth                     | 0.07 T or 0.030 [0.76],<br>whichever is less             | 0.10 T or 0.050 [1.3],<br>whichever is less              | 0.20 T or 0.070 [1.8],<br>whichever is less              |
| Accumulated length in any 3 in [75mm]<br>of weld maximum    | 0.20 [5.1]                                               | 0.60 [15]                                                | 1.00 [25]                                                |
| <b>Face or Root Underfill<sup>a</sup> (Groove Welds)</b>    |                                                          |                                                          |                                                          |
| For the full length of weld – maximum<br>depth              | 0.005 [0.13]                                             | 0.015 T or 0.005 [0.13]<br>whichever is greater          | 0.025 T or 0.005 [0.13]<br>whichever is greater          |
| Individual discontinuity – maximum<br>depth                 | 0.07 T or 0.030 [0.76]<br>whichever is less              | 0.10 T or 0.050 [1.3]<br>whichever is less               | 0.20 T or 0.070 [1.8]<br>whichever is less               |
| Accumulated length in any 3 in [75 mm]<br>of weld – maximum | 0.20 [5.1]                                               | 0.60 [15]                                                | 1.00 [25]                                                |
| <b>Craters</b>                                              |                                                          |                                                          |                                                          |
| Maximum depth                                               | 0.20 T or 0.03 [0.8]<br>whichever is less                | 0.20 T or 0.05 [1.3]<br>whichever is less                | 0.20 T or 0.05 [1.3]<br>whichever is less                |
| Maximum length                                              | 1 T                                                      | 1 T                                                      | 2 T                                                      |
| <b>Arc Strikes / Gouge Marks</b>                            | Not Allowed                                              | Not Allowed                                              | No stated requirement                                    |

(Continued)



**Table 7.1 (Continued)  
Acceptance Criteria (in [mm])**

| Discontinuity                                                                             | Class A                                                                                               | Class B                                                                                                  | Class C                                                                                                  |
|-------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| <b>Maximum Weld Reinforcement – mechanized and automated welds</b>                        |                                                                                                       |                                                                                                          |                                                                                                          |
| Material 0.375 [9.5] and under                                                            | 1/3 T or 0.030 [0.76]<br>whichever is greater                                                         | No stated requirement                                                                                    | No stated requirement                                                                                    |
| Material greater than 0.375 [9.5]                                                         | 0.125 [3.2]                                                                                           | No stated requirement                                                                                    | No stated requirement                                                                                    |
| <b>Maximum Weld Reinforcement—manual welds</b>                                            |                                                                                                       |                                                                                                          |                                                                                                          |
| Material 0.125 [3] and under                                                              | 1 T                                                                                                   | No stated requirement                                                                                    | No stated requirement                                                                                    |
| Material over 0.125 to 0.510 [3 to 13]                                                    | 1/3 T or 0.100 [2.5],<br>whichever is greater                                                         | No stated requirement                                                                                    | No stated requirement                                                                                    |
| Material greater than 0.510 [13]                                                          | 0.170 [4.3]                                                                                           | No stated requirement                                                                                    | No stated requirement                                                                                    |
| <b>Joint Penetration for Two or Three Member T-Joint for Melt-Through Welds</b>           | See Figure 7.3                                                                                        | See Figure 7.3                                                                                           | See Figure 7.3                                                                                           |
| <b>Mismatch between Members after welding</b>                                             | Refer to Paragraph 7.4.2.1 &<br>Figure 7.2. Includes A, B, & C<br>Class of Welds                      |                                                                                                          |                                                                                                          |
| <b>Fillet Weld Profiles</b>                                                               | Requirements of Figure 7.1                                                                            | Requirements of Figure 7.1                                                                               | Requirements of Figure 7.1                                                                               |
| <b>Angular Peaking</b>                                                                    | Requirements of 7.4.2.2                                                                               | Requirements of 7.4.2.2                                                                                  | Requirements of 7.4.2.2                                                                                  |
| <b>Fillet Weld Size – when fillet weld size is stated on the drawing</b>                  |                                                                                                       |                                                                                                          |                                                                                                          |
| Minimum size                                                                              | As shown by the welding symbol                                                                        | As shown by the welding<br>symbol                                                                        | As shown by the welding<br>symbol                                                                        |
| <b>Fillet Weld Size – minimum size when fillet weld size is not stated on the drawing</b> |                                                                                                       |                                                                                                          |                                                                                                          |
| Minimum size – single side fillet                                                         | 1.5 T                                                                                                 | 1.5 T                                                                                                    | 1.5 T                                                                                                    |
| Minimum size – double side fillet                                                         | 1 T                                                                                                   | 1 T                                                                                                      | 1 T                                                                                                      |
| <b>Fillet Weld Size – maximum size when fillet weld size is stated on the drawing</b>     |                                                                                                       |                                                                                                          |                                                                                                          |
| Material 0.090 [2.3] and under                                                            | 2 times the minimum fillet weld<br>size stated on the drawing or<br>0.090 [2.3], whichever is greater | 2 times the minimum fillet<br>weld size stated on the<br>drawing or 0.090 [2.3],<br>whichever is greater | 2 times the minimum fillet<br>weld size stated on the<br>drawing or 0.090 [2.3],<br>whichever is greater |
| Material 0.091 to 0.156 [2.31 to 4.0]                                                     | 1.5 times the minimum<br>fillet weld size                                                             | 1.5 times the minimum<br>fillet weld size                                                                | 1.5 times the minimum<br>fillet weld size                                                                |
| Material 0.157 to 0.750 [4.01 to 19]                                                      | 1.25 times the minimum<br>fillet weld size                                                            | 1.25 times the minimum<br>fillet weld size                                                               | 1.25 times the minimum<br>fillet weld size                                                               |
| Material greater than 0.751 [19]                                                          | 1.1 times the minimum<br>fillet weld size                                                             | 1.1 times the minimum<br>fillet weld size                                                                | 1.1 times the minimum<br>fillet weld size                                                                |
| <b>Discoloration<sup>c</sup> —Titanium</b>                                                |                                                                                                       |                                                                                                          |                                                                                                          |
| Bright Silver                                                                             | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Silver                                                                                    | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Light Straw                                                                               | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Dark Straw                                                                                | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Bronze                                                                                    | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Brown                                                                                     | Accept                                                                                                | Accept                                                                                                   | Accept                                                                                                   |
| Violet                                                                                    | Not Allowed <sup>d</sup>                                                                              | Accept                                                                                                   | Accept                                                                                                   |
| Blue                                                                                      | Not Allowed <sup>d</sup>                                                                              | Not Allowed <sup>c</sup>                                                                                 | Not Allowed <sup>c</sup>                                                                                 |
| Green                                                                                     | Not Allowed <sup>d</sup>                                                                              | Not Allowed <sup>c</sup>                                                                                 | Not Allowed <sup>c</sup>                                                                                 |
| Gray                                                                                      | Not Allowed                                                                                           | Not Allowed                                                                                              | Not Allowed                                                                                              |
| White                                                                                     | Not Allowed                                                                                           | Not Allowed                                                                                              | Not Allowed                                                                                              |

(Continued)

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**Table 7.1 (Continued)  
Acceptance Criteria (in [mm])**

| Discontinuity                                                   | Class A     | Class B     | Class C     |
|-----------------------------------------------------------------|-------------|-------------|-------------|
| <b>Discoloration—Stainless Steel, Nickel, and Cobalt Alloys</b> |             |             |             |
| All oxidation colors, except for Black                          | Accept      | Accept      | Accept      |
| Black discoloration or the presence of scale                    | Not Allowed | Not Allowed | Not Allowed |
| <b>Discoloration—Steel</b>                                      |             |             |             |
| All oxidation colors, except for Black                          | Accept      | Accept      | Accept      |
| Black                                                           | Not Allowed | Not Allowed | Not Allowed |

<sup>a</sup> For groove weld only.

<sup>b</sup> Discontinuity of size 0.005 in [0.13 mm] or less shall not be considered when determining compliance to the spacing requirements.

<sup>c</sup> Discoloration determined to be acceptable shall be removed prior to additional welding.

<sup>d</sup> This discoloration is acceptable on the base metal outside of 0.030" from the toe of the weld.

<sup>e</sup> Blue and green discoloration is not allowed if additional welding is to be performed. This discoloration is acceptable on finished welds but must be removed.

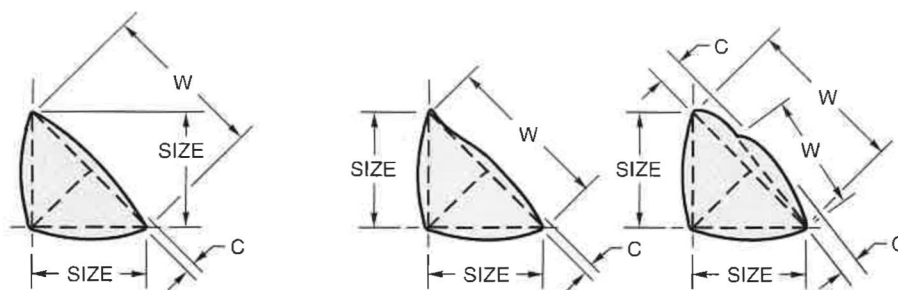
<sup>f</sup> Discoloration that is not allowed per the table may be determined acceptable through testing. Test methods, acceptance criteria and approval requirements shall be as specified by the Engineering Authority.

<sup>g</sup> Adjacent discontinuities that are acceptably-sized on an individual basis shall be considered as individual discontinuities when all of these apply:

- they are a cluster or group not in alignment
- they have a spacing less than the minimum allowed for the largest individual adjacent discontinuity
- the sum of the greatest dimensions of all discontinuities in the cluster or group is equal to or greater than the maximum allowable individual discontinuity size

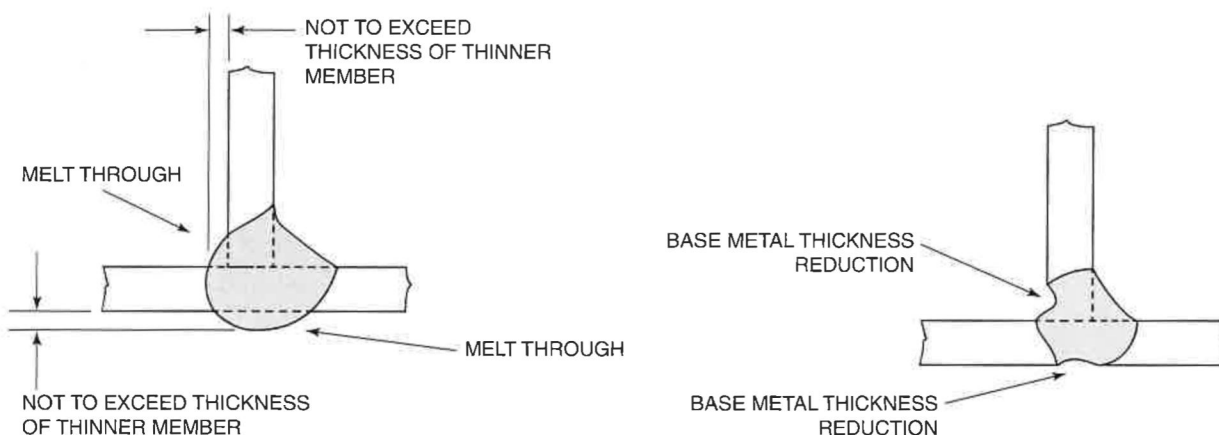
<sup>h</sup> Individual criteria not applicable for materials thinner than 0.028 in [0.7 mm], 0.020 in [0.5 mm], and 0.010 in [0.25 mm] for Classes A, B, and C, respectively. Use the criteria for entire weld.

<sup>i</sup> Individual criteria not applicable for materials thinner than 0.071 in [1.8 mm], 0.050 in [1.3 mm], and 0.025 in [0.6 mm] for Classes A, B, and C, respectively. Use the criteria for entire weld.



Requirement: Convexity, C, of a weld or individual surface bead with dimension W shall not exceed the value of the following table:

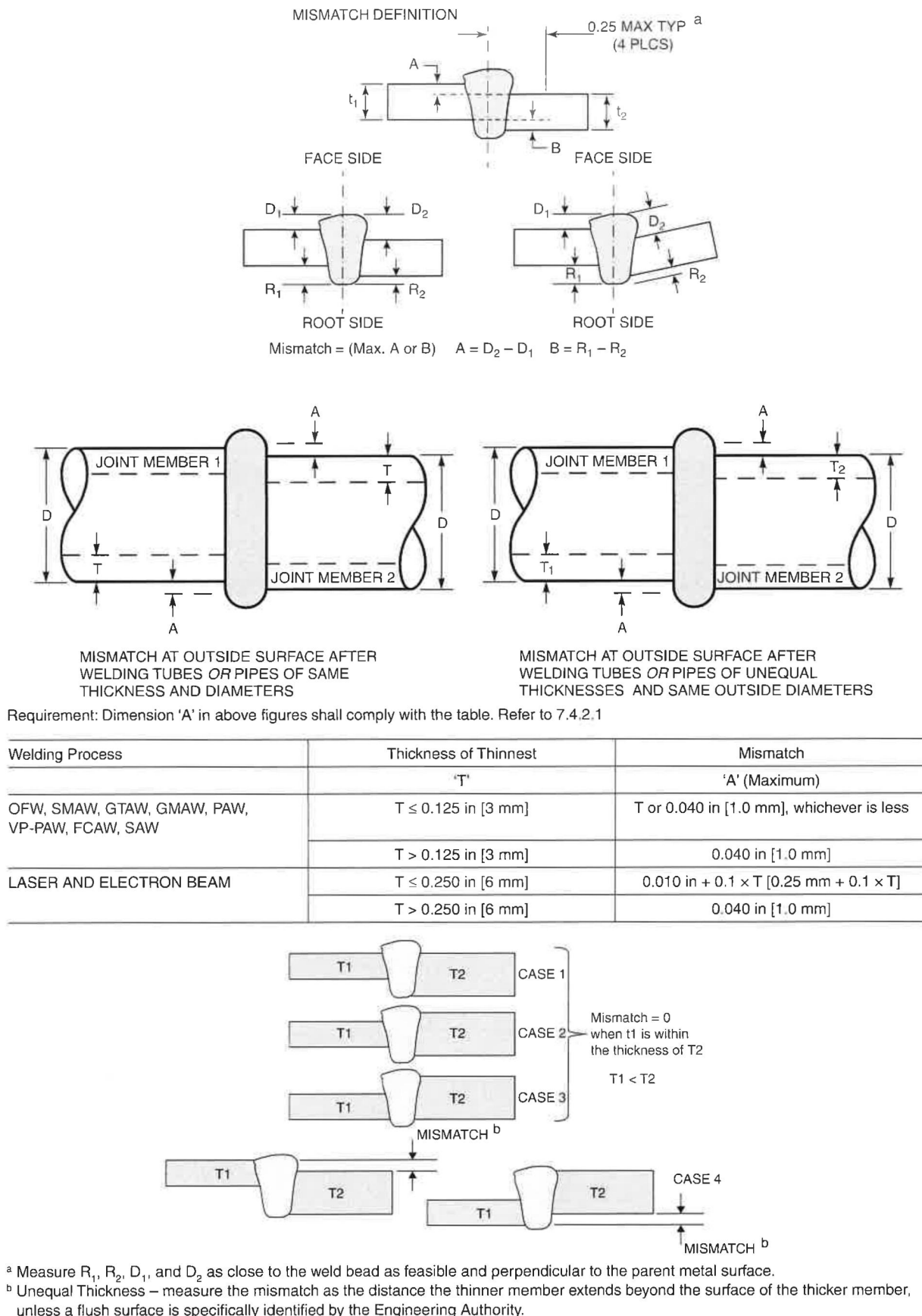
| Width of Weld Face or Individual Surface Bead, W | Max Convexity, C                                 |
|--------------------------------------------------|--------------------------------------------------|
| $W \leq 5/16$ in [7.9 mm]                        | $1/2 W$ or $1/16$ in [1.6 mm], whichever is less |
| $W > 5/16$ in [7.9 mm] TO $W < 1$ in [25 mm]     | $1/8$ in [3.2 mm]                                |
| $W \geq 1$ in [25 mm]                            | $3/16$ in [4.8 mm]                               |



Requirements:

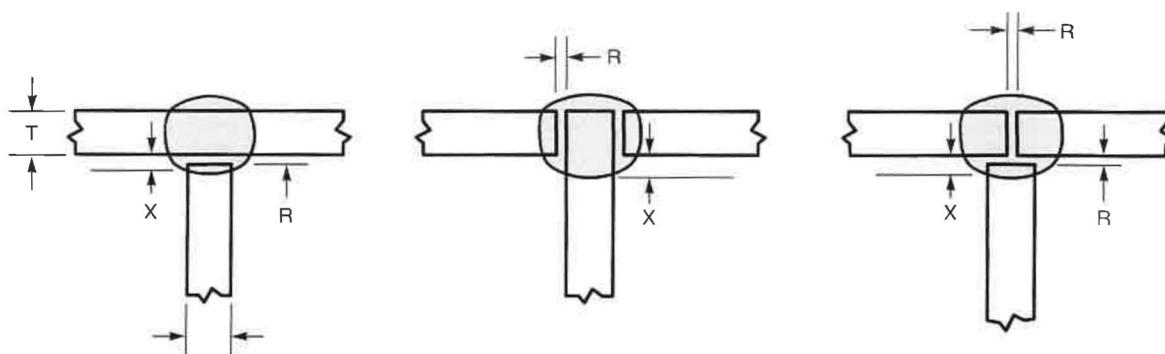
1. When thickness ( $T_1$  or  $T_2$ ) of any member is  $> 0.063$  in [1.6 mm], melt through evident at any sheet or tube surface opposite the weld bead shall be cause for rejection.
2. When thickness ( $T_1$  or  $T_2$ ) of any member is  $\leq 0.063$  in [1.6 mm], melt through evident at any sheet or tube surface opposite the weld bead face shall not exceed  $1T$  of the thinnest member.
3. In any material thickness, excessive melting shall not result in a reduction of material thickness.

**Figure 7.1—Fillet Weld Profiles**



**Figure 7.2—Mismatch Between Joint Members After Welding (See 7.4.2.1)**





Legend:

T = Thickness of thinner member

R = Root opening  $\leq 0.010$  in [0.25 mm] for  $T < 0.100$  in [2.5 mm],  $\leq 0.030$  in [0.76 mm] for  $T \geq 0.100$  in [2.5 mm]

X = Root Penetration

X (Minimum) =  $\frac{1}{2} T$  or 0.015 in [0.38 mm], whichever is greater

X (Maximum) =  $2 \frac{1}{2} T$  or 0.187 in [4.7 mm], whichever is less

**Figure 7.3—Two- and Three-Piece T-Weld Joints—Melt-Through Welds**

## 8. Repair of Existing Structures

**8.1 Scope.** This clause of the specification provides the requirements and applicability for weld repair procedures. Additionally, this clause applies only to the weld repair of in-service (existing) aerospace flight hardware and shall not be used for corrections encountered during original manufacturing. Welding procedure specifications used for the repair of existing structures and components shall meet the requirements of government approved Original Equipment Manufacturers (OEMs) or the appropriate repair manuals. Depending on the criticality of the weld repair, the stress analysis of the repair area and the repair procedure shall be approved by the appropriate governmental agency prior to weld repair.

**8.2 Design.** Repairs to existing structures shall be performed in accordance with the current regulatory requirements. Welding procedures and stress analysis are required for critical and semicritical structures. Documentation of stress analysis results shall be made available to the customer as defined by contract, or 7 years, whichever is longer.

**8.2.1 Classification.** The Engineering Authority shall classify the repair weld by considering the process controls, inspection, and acceptance criteria as described in Clause 1.4 of this specification. The classification selected may be more stringent than the original design but shall not be classified to lesser than the original design unless a stress analysis and mechanical testing data or component qualification has been performed. The stress analysis supporting the reduction of the weld classification shall be approved by the Engineering Authority per 8.2.

**8.2.2 Structures.** The Engineering Authority defines structures according to accepted practices and shall have the same meaning herein.

**8.2.2.1 Critical.** Welds made to critical structures shall have a stress analysis performed to determine the adequacy of the repair based on the location of the weld and type of weld. Consideration shall be given to prevent the weld from becoming a metallurgical or mechanical notch in critical structures.

**8.2.2.2 Semicritical.** Welds made to semicritical structures shall have a stress analysis performed prior to welding the structure.

**8.2.2.3 Noncritical.** Welds used for the repair of noncritical structures may have a stress analysis performed at the discretion of the Engineering Authority. Consideration should be given to performing a stress analysis if the weld repair is located in an area that may cause failure of the noncritical structure or loss of performance to the system.

### 8.3 Welding Procedures

**8.3.1 Qualification.** Welding procedures shall be qualified per Clause 5, and as modified herein. A previously qualified weld procedure may have the qualification extended for repair welding when authorized by the Engineering Authority.

**8.3.1.1** Procedure qualifications for weld repair of critical and semicritical structures shall be limited to the same base metal type, filler metal, and welding process used for the actual repair.

**8.3.1.2** Qualifying a welding procedure for weld repair of noncritical structures may be required at the discretion of the Engineering Authority.

**8.3.2 Techniques.** Welding techniques that contribute to the required design strength shall be included as qualification variables of the weld repair procedure of critical and semicritical structures. This includes, but is not limited to specifying and changing any of the following variables:

- (1) Qualification parameters or heat input
- (2) Bead width
- (3) Reinforcement
- (4) Welding sequence
- (5) Welding position
- (6) Filler metal strength
- (7) Welding process
- (8) Preweld and postweld heat treatments or aging
- (9) Preheat and interpass temperatures

Welding procedures that require qualification for purposes of developing a special technique shall have the welding techniques described in detail and shall become a part of the qualification variables of the welding procedure subject to requalification.

**8.4 Welder and Welding Operator Qualification.** Welders and Welding Operators shall be qualified per Clause 5 to perform welding using the equipment specified by the welding procedure.

**8.5 Welding Equipment.** Welding equipment shall meet the requirements of 6.3.

**8.6 Weld Repair Inspection.** Repair welding acceptance criteria shall be defined by the Engineering Authority or service manuals. As a minimum, the repair weld and the area within 0.5 in [13 mm] of the repair weld shall be inspected.

**8.6.1 Visual Weld Inspection.** All repair welds shall have a visual inspection performed by qualified personnel prior to performing other NDE techniques.

**8.6.2 Surface Inspections.** All repair welds shall have a final PT or MT inspection in accordance with the appropriate industry or customer specification (contingent upon magnetic properties regardless of criticality).

**8.6.3 Internal Inspection.** All repair welds to critical and semicritical structures regardless of the class of the weld shall have either RT or UT performed in accordance with the appropriate industry or customer specification.

**8.7 Grounding and Bonding.** Prior to welding on aircraft, an electrical ground path shall be approved by the Engineering Authority.

### 8.8 Repair Documentation

**8.8.1** All repair welds made to critical and semicritical structures shall be documented with the following information:

- (1) Location(s) (Drawing Number that will adequately identify the structure, using frame number, distance from identifiable lifting dimensions, etc.)
- (2) Repair dimensions and extent of repair(s)
- (3) Base and filler metal(s)
- (4) Process(es)
- (5) Procedure(s)
- (6) Welder(s)
- (7) Inspection method(s) and result(s)

**8.8.2 Record Maintenance.** Records of weld repairs shall be maintained in accordance with the requirements of the appropriate regulatory agency.

## 9. Nonflight Hardware

**9.1 Scope.** This clause establishes the minimum requirements for the design and fusion welding of nonflight hardware, except for pressure vessels. One of the following three options shall be used in the implementation of this clause, as determined by the Engineering Authority:

- (1) The codes and specifications listed in Table 9.1.
- (2) The codes and specifications listed in Table 9.1 with the exceptions and additions specified in this clause.
- (3) The requirements of Clauses 4–7 of this specification, with the exceptions and additions specified in Clause 9.

**9.2 Exceptions and Additional Requirements.** The following exceptions and additions are to be used with the applicable codes and specifications listed in Table 9.1, or with the requirements of Clauses 4–7 of this specification, when either option has been specified by the Engineering Authority.

**Table 9.1  
Industrial Codes and Specifications Suggested for Welding Aerospace Nonflight Hardware**

| Specification                     | Title                                                                                           |
|-----------------------------------|-------------------------------------------------------------------------------------------------|
| AWS D1.1/D1.1M                    | Structural Welding Code—Steel                                                                   |
| AWS D1.2/D1.2M                    | Structural Welding Code—Aluminum                                                                |
| AWS D1.3/D1.3M                    | Structural Welding Code—Sheet Metal                                                             |
| AWS D1.4/D1.4M                    | Structural Welding Code—Reinforcing Steel                                                       |
| AWS D1.5M/D1.5                    | Bridge Welding Code                                                                             |
| AWS D1.6/D1.6M                    | Structural Welding Code—Stainless Steel                                                         |
| AWS D1.9/D1.9M                    | Structural Welding Code—Titanium                                                                |
| AWS D3.6M                         | Specification for Underwater Welding                                                            |
| AWS D9.1M/D9.1                    | Sheet Metal Welding Code                                                                        |
| AWS D14.1/D14.1M                  | Specification for Welding Industrial and Mill Crane and Other Material Handling Equipment       |
| AWS D14.3/D14.3M                  | Specification for Welding Earthmoving, Construction, and Agricultural Equipment                 |
| AWS D14.4/D14.4M                  | Specification for Welded Joints in Machinery and Equipment                                      |
| AWS D14.5/D14.5M                  | Specification for Welding of Presses and Press Components                                       |
| AWS D14.6/D14.6M                  | Specification for Welding of Rotating Elements of Equipment                                     |
| AWS D14.7/D14.7M                  | Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls                  |
| AWS D14.8M (ISO/TR17844:2004 IDT) | Standard Methods for the Avoidance of Cold Cracks                                               |
| AWS D15.1/D15.1M                  | Railroad Welding Specification for Cars and Locomotives                                         |
| ASME B31.1                        | Code for Pressure Piping                                                                        |
| ASME B31.3                        | Process Piping                                                                                  |
| AWWA STD 100                      | Standard for Welded Steel-Elevated Tanks, Standpipes, and Reservoirs for Water Storage American |



**9.2.1 Joint Classifications.** The Engineering Authority shall specify the required weld design and inspection classification(s) on the engineering drawing. For structural welds, the design classifications shall be in accordance with the appropriate code or specification listed in Table 9.1, while the inspection classification shall be as follows: Class A, Class B, or Class C, in accordance with Clause 9.2.4.4. For welds in pressurized piping and tubing, the design and inspection classifications shall be in accordance with the applicable code or specification listed in Table 9.1 and with 9.2.4.4. The supplemental requirements of 9.2.4.4 pertain to the level of inspection required; the inspection procedures and acceptance criteria shall be in accordance with the applicable code or specification listed in Table 9.1. In cases where the codes and specifications in Table 9.1 do not address the specific materials being welded, Table 7.1 may be used for determining the inspection acceptance criteria.

## 9.2.2 Qualification

**9.2.2.1 General Requirements.** The fabricator shall be responsible for qualification of welders, welding operators, tack welders, and welding procedures prior to engaging in tacking and welding operations. Welders, welding operators, and tack welders may be qualified by the fabricator or an independent testing agency.

**9.2.2.2 Performance Qualification.** As an alternative to the requirements of the codes and specifications listed in Table 9.1, welders, welding operators, and tack welders engaged in the structural welding of nonflight hardware may be qualified in accordance with AWS B2.1.

*NOTE: This alternative does not extend to welders, welding operators, and tack welders engaged in the welding of pressurized piping and tubing in accordance with any applicable clause of ASME B31.1 or B31.3.*

**9.2.2.3 Procedure Qualification.** As an alternative to the requirements of the codes and specifications listed in Table 9.1, welding procedures to be used for the fabrication of Class A and Class B structural welds in nonflight hardware may be qualified in accordance with AWS B2.1.

*NOTE: This alternative does not extend to welding procedures used for the welding of pressurized piping and tubing in accordance with any applicable clause of ASME B31.1 or B31.3.*

## 9.2.3 Fabrication

**9.2.3.1 Calibration.** Welding equipment calibration requirements for automatic, mechanized, or robotic welding apparatus shall be in accordance with 6.3.1.

### 9.2.3.2 Welding Consumables

(1) **Identification.** The identification requirements for welding consumables shall be in accordance with 6.2.1.

(2) **Storage.** The storage requirements for welding consumables shall be in accordance with 6.2.2.

(3) **Consumable Inserts.** Consumable inserts shall be in accordance with AWS A5.30. Consumable inserts shall be of the same nominal composition as the filler metal to be used. No additional filler metal shall be added to a root pass when using a consumable insert.

(4) **Backing Rings in Pipe and Tubing for Fluid Applications.** With the exception of welds designated for ASME B31.3, Category D fluid service, backing rings shall not be used.

(5) **Shielding and Backing Gas.** Shielding and backing gas requirements shall be in accordance with 6.2.3, and as follows: inert gas backing is required for all joints when consumable inserts are used. The root of full penetration welds shall be suitably protected from oxidation or atmospheric contamination for the following material groups: aluminum, aluminum alloys, nickel, nickel alloys, stainless steels, titanium, and titanium alloys.

Inert gas backing should be maintained for the root pass and subsequent passes until the joint is completed, or a minimum of 0.2 in [5 mm] of weld metal thickness has been deposited.

**9.2.3.3 Preweld and Interpass Cleaning.** Preweld and interpass cleaning requirements shall be in accordance with 6.5.

**9.2.3.4 Preheating, Interpass Heating, and Postweld Heating.** Heating and maintaining the proper temperature specified on the engineering drawing or by the WPS may be accomplished by any suitable method capable of providing a uniform temperature throughout the part for a distance at least equal to the thickness of the thickest member (but not less than 3 in [75 mm] in all directions from the point of welding. For field applications, it is preferred that induction coils



or resistance heating braided “blankets” be used. When preheating is required, the joint shall be preheated prior to any welding, including tack welding. Temperatures shall be measured by suitable temperature-indicating methods that are accurate within  $\pm 25^{\circ}\text{F}$  [ $14^{\circ}\text{C}$ ].

**9.2.3.5 Filler Metals.** Filler metal requirements shall be in accordance with 6.12.

**9.2.3.6 Tack Welds.** Tack welds shall be used as required and shall be made by a qualified welder, welding operator, or tack welder. Tack welds shall be spaced symmetrically around or along the joint whenever possible. Chipping or grinding shall be blended to fair smoothly with the base metal. Tack welds that contain cracks or visible porosity shall not be fused with the root pass and shall be removed in accordance with 9.2.5.1.

**9.2.3.7 Weld Bead Initiation and Termination.** Weld start and run-off tabs shall be used whenever a weld pass meets the end of a joint, with exception as approved prior to fabrication by the Engineering Authority. Weld tabs shall be made of the same material as the parts being welded. When start or run-off tabs cannot be used, the areas of initiation and termination of each weld bead shall be chipped or ground as necessary to remove any visible defects in the weld metal before depositing any subsequent weld beads. In addition, ground area shall be blended to fair smoothly with the adjacent base metal. Unless otherwise specified by the Engineering Authority, weld beads shall not terminate at inside corners or notches, or in other critical areas such as changes in welding direction or sudden changes in section thickness. For reference purposes, the point of termination is located where the weld metal protrudes furthest along the joint line.

**9.2.3.8 Backgouging.** All groove welded joints that are to be welded from both sides and require 100% penetration shall be back gouged to sound metal prior to the welding of the second side. Whenever possible, two or three passes shall be deposited on the first side prior to the gouging of the backside. Backgouging to sound metal may be done by machining, chisel, grinder, arc gouging, or by other appropriate methods. Gouged areas shall be blended to fair smoothly with the adjacent metal.

**9.2.3.9 Postweld Cleaning.** Postweld cleaning requirements shall be in accordance with 6.15.

**9.2.3.10 Identification of Welds.** Appropriate records shall be maintained that identify the welds made by each qualified welder and welding operator. These records shall be made available to the Engineering Authority when required by contract documentation.

## **9.2.4 Inspection**

**9.2.4.1 General.** The fabricator is responsible for the performance of all inspections, tests, and quality control requirements as specified herein. The fabricator may utilize his own or any other testing laboratory acceptable to and approved by the Engineering Authority for the performance of all required destructive and nondestructive inspections.

The visual and nondestructive inspections described herein shall apply to completed welds and the adjacent base metal up to a minimum of 0.5 in [13 mm] from both sides of the edge of the deposited weld metal. Welds that do not satisfy the acceptance criteria of the appropriate code or specification listed in Table 9.1 shall be reworked in accordance with 9.2.5.

**9.2.4.2 Qualification of NDE Personnel.** NDE personnel qualification requirements shall be in accordance with 7.1.

**9.2.4.3 Visual Inspection.** All welds shall be visually inspected for conformation to the drawing requirements and to the requirements of either the appropriate code or specification listed in Table 9.1, or the requirements of Table 7.1.

### **9.2.4.4 NDE of Nonflight Hardware**

(1) **Class A Inspection (for structural welds only).** In addition to the required visual inspection, all Class A inspections shall require 100% radiographic testing (RT) and either 100% magnetic particle testing (MT) or 100% liquid penetrant testing (PT) in accordance with the appropriate codes or specifications listed in Table 9.1. Ultrasonic testing (UT) may be used in lieu of RT at the Engineering Authority’s discretion.

(2) **Class B Inspection (for structural welds only).** In addition to the required visual inspection, all Class B inspections shall require either 100% MT or 100% PT in accordance with the appropriate codes or specifications listed in Table 9.1. When producing multipass welds in thick sections, it is recommended that the root pass, final pass, and each 0.5 in [13 mm] interval of thickness be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. RT may be used at the Engineering Authority’s discretion.

(3) **Class C Inspection (for structural welds only).** All Class C inspections require only the visual inspection described in 9.2.4.3. MT and/or PT may be used at the Engineering Authority’s discretion.

(4) **Welds in Piping and Tubing for Fluid Service.** When this specification is used in conjunction with ASME B31.3, all piping and tubing welds shall undergo NDE in accordance with the applicable fluid service inspection requirements of ASME B31.3.

(5) **In-Process Examination for Automatic Gas Tungsten Arc Welding (GTAW).** With the exception of welds designated for High Pressure and Category M Fluid Service per ASME B31.3, an in-process examination may be substituted for the required RT of piping and tubing welds made using a fully automatic GTAW process only. In addition to the in-process examination requirements defined in ASME B31.3, the following additional requirements shall be satisfied:

(a) The in-process examination shall be applied to all welds.

(b) The automatic GTAW process parameters shall be strictly monitored and recorded; if these parameters exceed plus or minus 10% of the qualified values established during the welding procedure qualification, the affected weld shall require RT. The process parameters to be monitored and recorded shall include the following:

- (i) Arc current
- (ii) Pulse high current
- (iii) Pulse low current
- (iv) Pulse high time
- (v) Pulse low time
- (vi) Start slope
- (vii) Finish slope
- (viii) Rotation delay
- (ix) Head speed (rpm)
- (x) Shielding and backing gas flow rate
- (xi) Arc voltage
- (xii) Tungsten electrode (position, length, bevel, land, arc length)

(c) Welds classified as subject to Severe Cyclic Conditions shall require 100% PT or 100% MT.

*NOTE: All NDE materials (e.g., liquid penetrants, developers, ultrasonic couplants, etc.) that are to be applied to surfaces that will be exposed to oxygen (gaseous or liquid) or hypergols in-service shall be compatible with that service fluid. Oxygen compatibility shall be determined in accordance with procedures approved by the Engineering Authority.*

**9.2.4.5 Alternate Inspection Methods.** In cases where the joint configuration makes it impractical to obtain a satisfactory radiograph (e.g., a fillet weld) a satisfactory alternate method of NDE shall be approved by the Engineering Authority. If PT or MT is proposed to be used in lieu of RT, then the root pass, final pass, and each 0.5 in [13 mm] interval of thickness shall be inspected. In addition to the normal interpass cleaning requirements for multipass welds, all liquid penetrant materials and/or metal particles shall be removed after each such inspection. In cases where adequate postweld inspection cleaning is difficult to achieve (e.g., inner lines of vacuum-jacketed systems, intermediate passes of multipass welds in aluminum), PT may be selectively omitted if approved by the Engineering Authority (e.g., a visual inspection, RT, and a proof test of an inner line in a vacuum-jacketed cryogenic system could be considered sufficient without PT). Also, PT of just the final pass of a multipass aluminum weld could be considered sufficient. The necessity of selectively omitting PT, as well as the necessity and acceptability of any proposed alternate NDE methods, should be agreed upon by the fabricator and the Engineering Authority.

**9.2.4.6 Proof Testing.** Proof testing may be used in conjunction with or in lieu of the required NDE if approved by the Engineering Authority.

**9.2.4.7 Etching for PT.** Weldments in soft metals (i.e., aluminum alloys, magnesium alloys, etc.) that are machined, ground, sanded, abraded, or otherwise mechanically worked to cause smearing or disruption of the metal surface shall be etched to remove the masking material prior to penetrant application. Etching is not required for those features such as close tolerance surfaces, faying surfaces, etc., where the function of the component or assembly would be degraded.

**9.2.4.8 Penetrant Testing (PT) Allowable Type.** Welds may be penetrant tested using any approved Type I or II penetrant systems.



### 9.2.5 Weld Rework

**9.2.5.1 Discontinuity Removal.** Portions of weld and/or base metal containing rejectable discontinuities shall be removed to sound metal. The use of mechanical means (e.g., grinding, chipping, or machining) is preferred. After the removal of any metal containing discontinuities, and prior to re-welding, the joint shall be re-inspected to ensure that the discontinuities have been completely removed, using the same inspection method and acceptance criteria used to detect the original discontinuity.

**9.2.5.2 Rework Procedure.** The rework welding procedure shall be the same as the original qualified WPS or an approved qualified repair process, recognizing that the cavity to be repaired may differ in contour and dimensions from the original joint. With the exception of Class C structural welds and Category D Fluid Service welds (per ASME B31.3), no more than two attempts shall be made to rework a weld discontinuity; further rework attempts require the approval of the Engineering Authority. The completed reworked weld shall be inspected to the same requirements and acceptance criteria as the original weld.

**9.2.5.3 Rework Records.** The fabricator shall prepare and maintain records of all weld reworks in Class A and B welds and shall make these records available to the Engineering Authority.

## 10. Crewed Spaceflight Hardware

**10.1 Scope.** This clause covers the additional requirements for the welding, fabrication, and inspection of welds of crewed spaceflight hardware, including launch vehicles. This clause may be invoked for uncrewed missions if directed by the Engineering Authority.

**10.2 General.** Application of this clause shall be specified on the engineering drawing as "IN ACCORDANCE WITH AWS D17.1, CLAUSE 10, CREWED SPACEFLIGHT HARDWARE." When this clause is invoked via engineering drawing or procurement specification, requirements of Clauses 1-8 shall also apply.

**10.2.1 Class A Applications.** Fracture critical welds shall comply with Class A requirements.

**10.2.1.1 Manual Welding.** Class A manual weld parameters and operating parameter ranges shall be established via WPS qualification.

**10.2.1.2 Penetrant Testing (PT).** In addition to the requirements for Class A welds per 7.3.1, penetrant testing shall be conducted using sensitivity level 3 or better.

**10.2.2 Class B Applications.** Structural welds that are considered to be fail safe but are not fracture critical shall comply with Class B requirements as a minimum.

**10.2.2.1 Manual Welding.** Class B manual weld parameters and operating parameter ranges shall be established via WPS qualification.

**10.2.2.2 Penetrant Testing (PT).** In addition to the requirements for Class B welds per 7.3.1, penetrant testing shall be conducted using sensitivity level 3 or better.

**10.2.3 Class C Applications.** Non-fracture critical, non-structural welds shall comply with Class C requirements at a minimum (including seal welds).

**10.2.4 No Class Designated.** If no class is designated on a drawing, Class A requirements shall apply.

### 10.3 Welding Processes.

**10.3.1 Electron Beam Welding.** Electron beam welding shall comply with SAE AMS2680.

**10.4 Approval of Engineering Authority.** The following welding practices shall require approval of the Engineering Authority to document the acceptance rationale:

1. Welding from both sides if full penetration of the first pass is not verified (either by inspection of the root side for complete fusion or by backgouging prior to welding on the second side).
2. Partial penetration groove welds or fillet welds with Class A or Class B designations.
3. Straightening operation after welding.

4. Lap joints in Class A or Class B applications.
5. The use of proof testing in lieu of NDE (as described in Clause 7.3.5).
6. Welding heat-treatable alloys (such as precipitation hardened stainless steel and solution treated nickel alloys), where no post weld heat treatment can be performed.

**10.5 WPS & Qualification Requirements.** The Welding Procedure Specification (WPS) shall include the following content in addition to that required by Clause 5.

1. The maximum allowed in-process correction or rework attempts shall be as qualified by the PQR and included in the WPS. The completed reworked weld shall be inspected to the same requirements and acceptance criteria as the original weld.

2. Procedure Qualification Record (PQR) with tension test results (or equivalent mechanical testing) and metallographic examination results. The numbers of tests shall be in accordance with Table 5.3.

*NOTE: Qualification strength requirements should be included in weld qualification test acceptance. Qualification strength values are not the same as materials design allowables.*

**10.6 Material Review Board.** Discrepant hardware shall be submitted to the Material Review Board. Some examples requiring MRB include:

1. Incorrect filler metal used.
2. More than the number of rework attempts per 6.19.1 and as qualified by 10.5 (1).
3. Repair weld required after the weldment has been post weld heat treated.
4. Repair weld required after final machining has been completed.
5. Weld repair extends outside the original weld metal and heat affected zones.
6. Welds repairs following proof or leak test.

#### **10.7 Titanium Welding.**

*NOTE: AWS G2.4/G2.4M "Guide for the Fusion Welding of Titanium and Titanium Alloys" should be used for guidance on titanium welding.*

**10.7.1 Discoloration.** Evaluate titanium welds in accordance with Table 7.1, except only bright silver, silver, light straw, and dark straw colors are acceptable.

**10.7.2 Titanium Filler Metals.** Titanium and its alloys shall be welded autogenously or with metallurgically compatible fillers, as specified by the engineering drawing. Commercially Pure (CP) titanium filler should not be used on Ti-6Al-4V or other alloyed base material. Ti-6Al-4V filler metal is metallurgically compatible with Ti-3Al-2.5V.

**10.7.3 Cryogenic Applications.** Extra Low Interstitial (ELI) filler wires shall be used for cryogenic applications where temperatures are less than -198° F [-128° C]. ELI filler wires are preferred for general applications.

#### **10.7.4 Shielding Gas.**

**10.7.4.1.** Nitrogen, hydrogen, carbon dioxide, or mixtures containing these gases shall not be used in welding titanium and its alloys.

**10.7.4.2.** Inert shielding gas shall have a dew point of -60° C (-76° F) or lower.

#### **10.7.5 Stress Relief.**

(1) Welded alpha and alpha plus beta alloys shall be stress relieved in a vacuum or inert gas environment (Ar or He), or stress relieved in air with verification of oxide removal per AMS-H-81200 or AMS2801. Hardware in the as-welded condition is acceptable when approved by the Engineering Authority.

(2) Beta alloys that are welded shall be evaluated and approved by the Engineering Authority for stress relief requirements.



## Annex A (Informative)

### Guidelines for Design, Analysis, and Fabrication of Weld Joints

This annex is not part of this standard but is included for informational purposes only.

#### A1. Scope

The following information and figures are provided as standard design information. These joint designs and dimensions are based on widespread use in the aerospace industry with satisfactory results. However, it is incumbent upon the Engineering Authority that if these designs are used sufficient engineering analysis is performed for the application.

Fabricators—The Engineering Authority may require fabricators to comply with the requirements of this Annex for fitup.

#### A2. Groove Welds

The designer may use the standard joint details given in Figure A.1 for complete joint penetration groove welds and Figure 7.3 for complete penetration groove welds in two- and three-piece tee joints.

**A2.1 Groove Weld Effective Area.** The effective area is the effective weld length multiplied by the weld size. The effective weld length for any groove weld, perpendicular or nonperpendicular (square or skewed), should be the width of the part joined perpendicular to the direction of stress. The weld size of a complete joint penetration groove weld should be the thickness of the thinner part joined. Weld reinforcements do not increase the effective area of the weld.

#### A3. Edge Welds in Flanged Joints

**A3.1** The designer may use the standard joint details given in Figure A.2.

#### A4. Fillet Welds

**A4.1 Fillet Weld Size.** The efficiency of the weld joint is based on the strength of the weaker member being joined. It is based on member thickness multiplied by the base metal ultimate tensile strength. To achieve 100% joint efficiency using an equivalent strength filler metal the weld size must be a minimum of 70% of the base metal thickness for a double-sided weld, and 140% for a single-sided weld. The suggested minimum weld size for a single fillet weld is 1.5 times the thickness of the thinner member being joined. The suggested minimum weld size for double fillet welds is 1.0 times the thickness of the thinner member being joined. However, when dynamic loading conditions are present, the Engineering Authority should assure that the required fillet weld size is suitable for the design application.

For lap and corner joints, when the maximum size fillet weld is required, a convex fillet, the size of the thinnest member should be specified on the drawing ( $E = S$ ). See Figure A.3.

The relationship of the effective throat to weld size is shown in Figure A.3. Correction factors for fillet welds in skewed T-joints are given in Table A.1 for dihedral angles ( $\Psi$ ) between 60 degrees and 135 degrees.

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#### A4.2 Fillet Weld Effective Throat

**A4.2.1 Calculation.** The effective throat of a fillet weld is the shortest distance from the joint root to the weld face. No strength allowance should be given in the design calculations for root penetration unless a combination groove and fillet weld is specified for the joint.

**A4.2.2 Shear Stress.** Stress on the effective throat of a fillet weld is considered as shear stress regardless of the load direction.

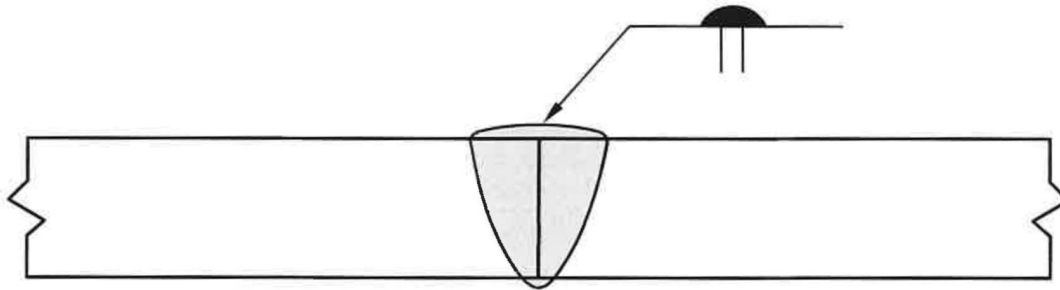
#### A4.3 Fillet Weld Length

**A4.3.1 Effective Length (Straight).** The effective length of a fillet weld should be the overall length of the full-size fillet including boxing. No reduction in effective length should be made for either the start of the weld or the end, in the design calculations.

**A4.3.2 Effective Length (Curved).** The effective length of a curved fillet weld should be measured along the centerline of the effective throat. If the weld area of a fillet weld in a hole or a slot computed from this length is greater than the area of the hole in the plane of the faying surface, then the area of the hole should be used as the effective area of the fillet weld.

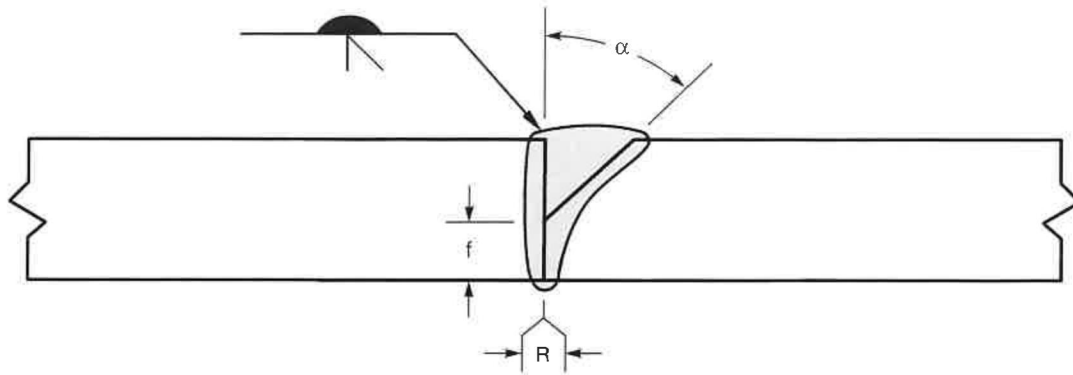
**A4.3.3 Fillet Weld Minimum Length.** The minimum effective length of a fillet weld should be at least four times the nominal size.

**A4.4 Fillet Weld Effective Area.** The effective area should be the effective length multiplied by the effective throat.



| Weld Process | Base Metal Thickness "T" (in [mm])                                                                                            | Max Root Opening [R] (in [mm])                                                                | Material | Remarks           |
|--------------|-------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|----------|-------------------|
| GTAW         | 0.090 [2.5] max                                                                                                               | 1/2 T or 0.045 [1.1], whichever is less                                                       | Any      | Manual GTAW       |
|              | 0.125 [3] max                                                                                                                 | 1/4 T or 0.030 [0.76], whichever is less                                                      | Any      | Mechanized GTAW   |
|              | 0.250 [6] max                                                                                                                 |                                                                                               | Al or Ti | Mechanized GTAW   |
| PAW          | 0.375 [10] max                                                                                                                | 1/4 T or 0.030 [0.76], whichever is less                                                      | Al or Ti | Mechanized PAW    |
|              |                                                                                                                               | 0.040 [1.02] max                                                                              | Al or Ti | Mechanized VP-PAW |
| EBW          | ≤0.030 [0.7]<br>0.031–0.100 [0.71–2.5]<br>0.101–0.200 [2.51–5]<br>0.201–0.300 [5.1–8]<br>0.301–0.400 [8.1–10]<br>>0.400 [>10] | 0.002 [0.051]<br>0.005 [0.13]<br>0.007 [0.18]<br>0.008 [0.20]<br>0.009 [0.23]<br>0.010 [0.25] | Any      |                   |
| LBW          |                                                                                                                               | 1/8 T or 0.005 [0.13], whichever is less                                                      | Any      |                   |

**Figure A.1(a)—Square Groove Butt Joints**



| Weld Process        | Base Metal Thickness [T] (in [mm]) | Root Opening [R] (in [mm]) Max. | Root Face [f] (in [mm]) |                                | Groove Angle [α] (degrees) |                                       |
|---------------------|------------------------------------|---------------------------------|-------------------------|--------------------------------|----------------------------|---------------------------------------|
| GTAW                | 0.060–0.500 [1.5–13]               | ≤0.030 [0.76]                   | 0.030 [0.76]            | +0.030 [0.76]<br>–0.000 [0.00] | 60°                        | +10°<br>–5°                           |
| PAW <sup>a</sup>    | 0.060–0.500 [1.5–13]               | ≤0.030 [0.76]                   | 0.030 [0.76]            | +0.030 [0.76]<br>–0.000 [0.00] | 60°                        | +10°<br>–5°                           |
| GMAW<br>FCAW<br>SAW | 0.060 [1.5] – unlimited            | ≤0.030 [0.76]                   | 0.060 [1.52]            | +0.030[0.76]<br>–0.000 [0.00]  | 45°<br>60°                 | +10° <sup>b</sup><br>–5° <sup>c</sup> |

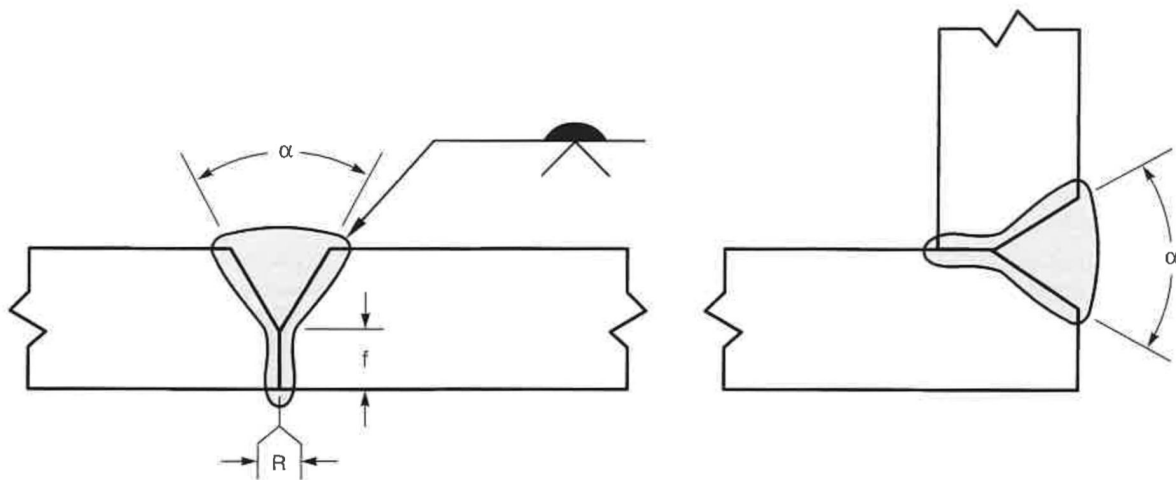
<sup>a</sup> Non-keyhole mode only.

<sup>b</sup> Applicable to ferrous, heat resistant, and magnesium alloys.

<sup>c</sup> Applicable to aluminum and titanium alloys.

**Figure A.1(b)—Single-Bevel-Groove Weld Joints**

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| Weld Process        | Base Metal Thickness [T] (in [mm]) | Root Opening [R] (in [mm]) Max. | Root Face [f] (in [mm])                        | Groove Angle [ $\alpha$ ] (degrees) |
|---------------------|------------------------------------|---------------------------------|------------------------------------------------|-------------------------------------|
| GTAW                | 0.060–0.500 [1.5–13]               | $\leq 0.030$ [0.76]             | 0.030 [0.76]<br>+0.030 [0.76]<br>–0.000 [0.00] | 60°<br>+10°<br>–5°                  |
| PAW <sup>a</sup>    | 0.060–0.500 [1.5–13]               | $\leq 0.030$ [0.76]             | 0.030 [0.76]<br>+0.030 [0.76]<br>–0.000 [0.00] | 60°<br>+10°<br>–5°                  |
| GMAW<br>FCAW<br>SAW | 0.060 [1.5] – unlimited            | $\leq 0.030$ [0.76]             | 0.060 [1.52]<br>+0.030 [0.76]<br>–0.000 [0.00] | 45°<br>+10°<br>–5° <sup>b</sup>     |
|                     |                                    |                                 |                                                | 60°<br>+10°<br>–5° <sup>c</sup>     |

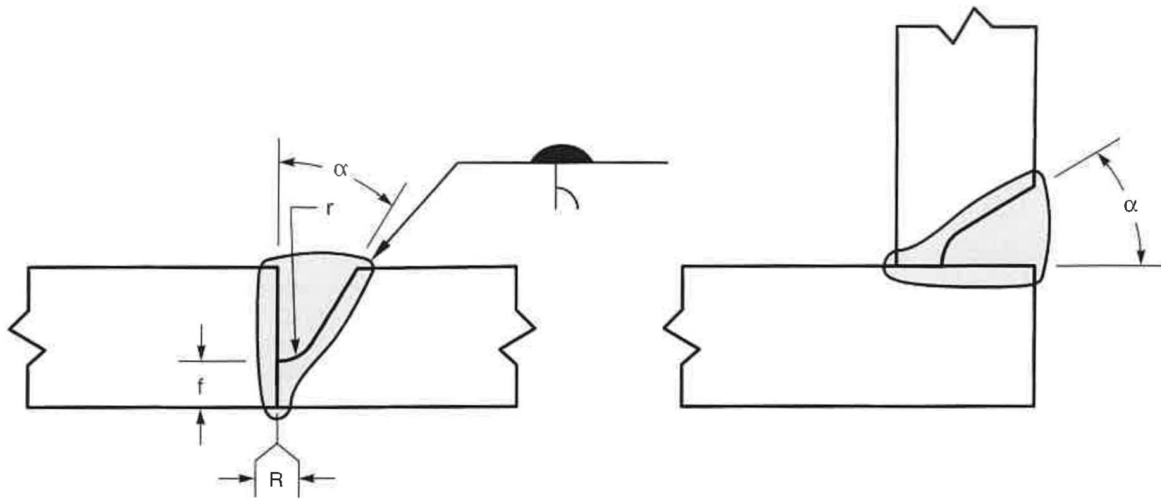
<sup>a</sup> Non-keyhole mode only.

<sup>b</sup> Applicable to ferrous, heat-resistant alloys, and magnesium alloys.

<sup>c</sup> Applicable to aluminum and titanium alloys.

**Figure A.1(c)—Single-V-Groove Weld Joints**



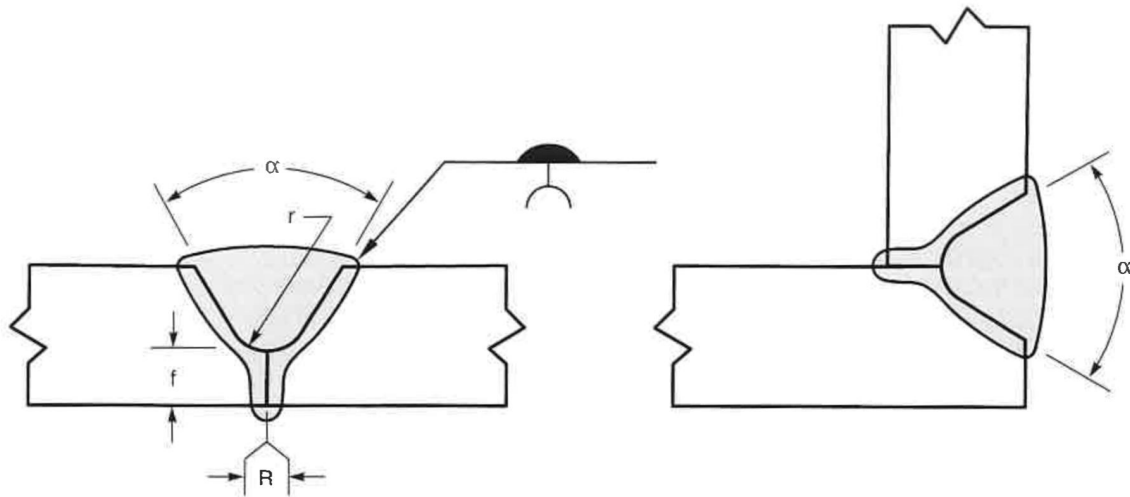


| Weld Process        | Base Metal Thickness [T] (in [mm]) | Max Root Opening [R] (in [mm]) | Root Face [f] (in [mm]) |                                 | Groove Angle [ $\alpha$ ] (degrees) |             | Groove Radius (r) (in [mm]) |                                |
|---------------------|------------------------------------|--------------------------------|-------------------------|---------------------------------|-------------------------------------|-------------|-----------------------------|--------------------------------|
| GTAW                | 0.501–0.700 [13.1–18]              | $\leq 0.030$ [0.76]            | 0.030 [0.76]            | +0.030 [0.76]<br>–0.000 [0.00]  | 30°                                 | +10°<br>–5° | 0.38 [9.7]                  | 0.030 [0.76]<br>–0.010 [0.25]  |
|                     | >0.700 [18]                        | $\leq 0.030$ [0.76]            | 0.030 [0.76]            | +0.030 [0.76]<br>–0.000 [0.00]  | 30°                                 | +10°<br>–5° | 0.44 [11.2]                 | +0.030 [0.76]<br>–0.010 [0.25] |
| PAW <sup>a</sup>    | 0.501–0.700 [13.1–18]              | $\leq 0.030$ [0.76]            | 0.030 [0.76]            | +0.030 [0.76]<br>–0.010 [0.025] | 30°                                 | +10°<br>–5° | 0.38 [9.7]                  | +0.030 [0.76]<br>–0.010 [0.25] |
|                     | >0.700 [18]                        | $\leq 0.030$ [0.76]            | 0.030 [0.76]            | +0.030 [0.76]<br>–0.010 [0.025] | 30°                                 | +10°<br>–5° | 0.44 [11.2]                 | +0.030 [0.76]<br>–0.010 [0.25] |
| GMAW<br>FCAW<br>SAW | 0.501–0.700 [13.1–18]              | $\leq 0.030$ [0.76]            | 0.060 [1.5]             | +0.030 [0.76]<br>–0.030 [0.76]  | 30°                                 | +10°<br>–5° | 0.38 [9.7]                  | +0.030 [0.76]<br>–0.010 [0.25] |
|                     | >0.700 [18]                        | $\leq 0.030$ [0.76]            | 0.060 [1.5]             | +0.030 [0.76]<br>+0.030 [0.76]  | 30°                                 | +10°<br>–5° | 0.44 [11.2]                 | –0.030 [0.76]<br>–0.010 [0.25] |

<sup>a</sup> Non-keyhole mode only.

Figure A.1(d)—Single-J-Groove Weld Joints

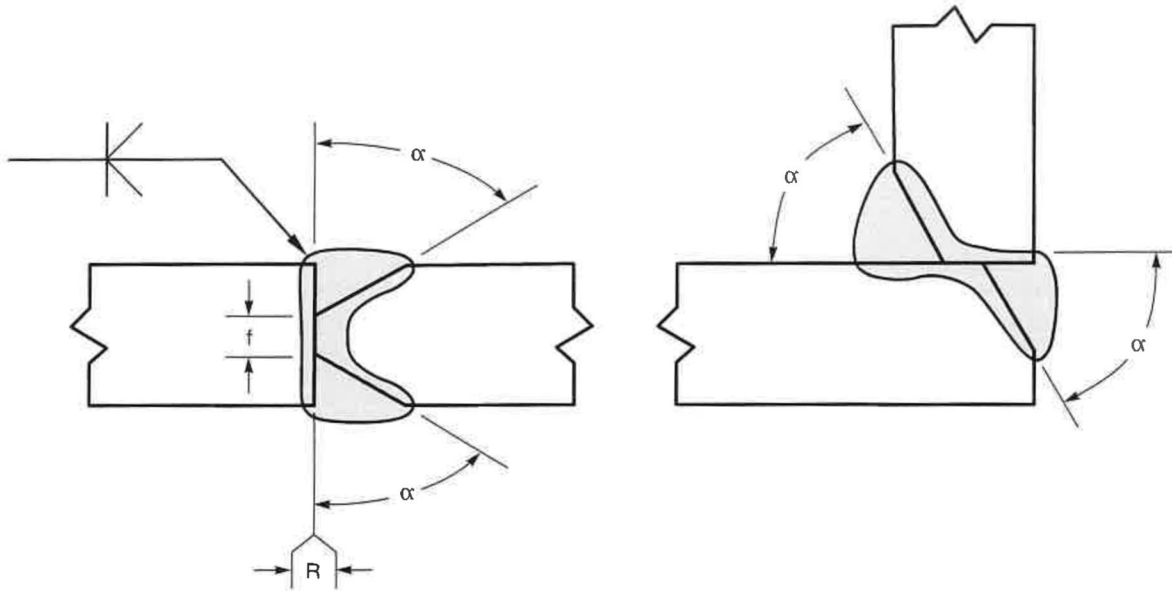
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| Weld Process        | Base Metal Thickness [T] (in [mm]) | Max Root Opening [R] (in [mm]) | Root Face [f] (in [mm]) |                                | Groove Angle [α] (degrees) |             | Groove Radius (r) (in [mm]) |                                |
|---------------------|------------------------------------|--------------------------------|-------------------------|--------------------------------|----------------------------|-------------|-----------------------------|--------------------------------|
| GTAW                | >0.400 [10]                        | ≤0.030 [0.76]                  | 0.030 [0.76]            | +0.030 [0.76]<br>-0.000 [0.00] | 20°                        | +10°<br>-5° | 0.250 [6]                   | +0.030 [0.76]<br>-0.010 [0.25] |
| PAW <sup>a</sup>    | >0.400 [10]                        | ≤0.030 [0.76]                  | 0.030 [0.76]            | +0.030 [0.76]<br>-0.000 [0.00] | 20°                        | +10°<br>-5° | 0.250 [6]                   | +0.030 [0.76]<br>-0.010 [0.25] |
| GMAW<br>FCAW<br>SAW | >0.400 [10]                        | ≤0.030 [0.76]                  | 0.060 [1.5]             | +0.030 [0.76]<br>-0.010 [0.25] | 20°                        | +10°<br>-5° | 0.250 [6]                   | +0.030 [0.76]<br>-0.010 [0.25] |

<sup>a</sup> Non-keyhole mode only.

Figure A.1(e)—Single-U-Groove Weld Joints



| Weld Process                     | Base Metal Thickness [T]<br>(in [mm]) | Max Root Opening [R]<br>(in [mm]) | Root Face [f]<br>(in [mm]) <sup>a</sup>       | Groove Angle [α] (degrees)     |
|----------------------------------|---------------------------------------|-----------------------------------|-----------------------------------------------|--------------------------------|
| GTAW <sup>b</sup>                | 0.250–1.000 [6–25]                    | ≤ 0.030 [0.76]                    | 0.030 [0.76] + 0.030 [0.76]<br>– 0.010 [0.25] | 60° + 10°<br>– 5°              |
| PAW <sup>c,b</sup>               | 0.250–1.000 [6–25]                    | ≤ 0.030 [0.76]                    | 0.030 [0.76] + 0.030 [0.76]<br>– 0.010 [0.25] | 60° + 10°<br>– 5°              |
| GMAW <sup>b</sup><br>FCAW<br>SAW | 0.250–1.000 [6–25]                    | ≤ 0.030 [0.76]                    | 0.060 [1.5] + 0.030 [0.76]<br>– 0.010 [0.25]  | 45° + 10°<br>– 5° <sup>d</sup> |
|                                  |                                       |                                   |                                               | 60° + 10°<br>– 5° <sup>e</sup> |

<sup>a</sup> Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

<sup>b</sup> Back-gouging to sound metal is required before welding second side.

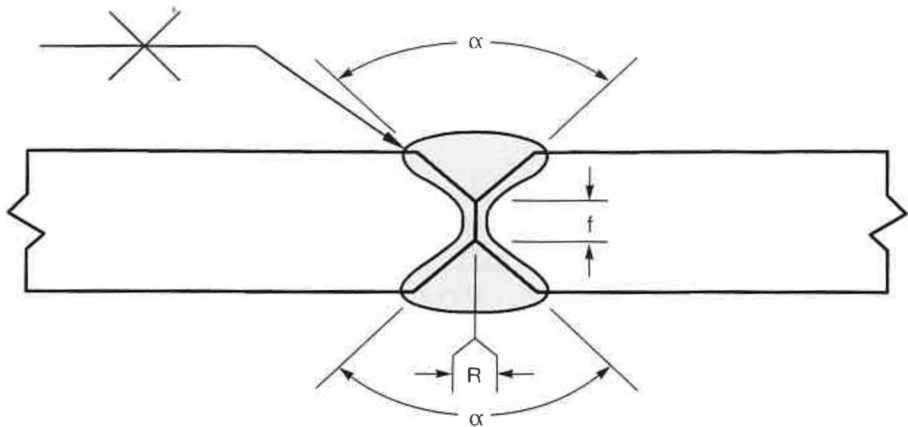
<sup>c</sup> Non-keyhole mode only.

<sup>d</sup> Applicable to ferrous, heat resistant, and magnesium alloys.

<sup>e</sup> Applicable to aluminum and titanium alloys.

**Figure A.1(f)—Double-Bevel-Groove Weld Joints**

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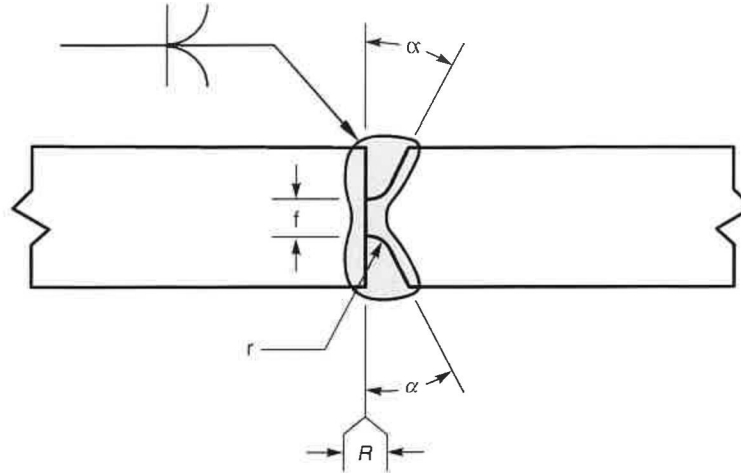


| Weld Process       | Base Metal Thickness [T] (in [mm]) | Max Root Opening [R] (in [mm]) | Root Face [f] (in [mm]) <sup>a</sup> |                                  | Groove Angle [α] |                            |
|--------------------|------------------------------------|--------------------------------|--------------------------------------|----------------------------------|------------------|----------------------------|
| GTAW               | 0.250–1.000 [6–25]                 | ≤ 0.030 [0.76]                 | 0.030 [0.76]                         | + 0.030 [0.76]<br>– 0.010 [0.25] | 60°              | + 10°<br>– 5°              |
| PAW <sup>b,c</sup> | 0.250–1.000 [6–25]                 | ≤ 0.030 [0.76]                 | 0.030 [0.76]                         | + 0.030 [0.76]<br>– 0.010 [0.25] | 60°              | + 10°<br>– 5°              |
| GMAW <sup>c</sup>  | 0.250–1.000 [6–25]                 | ≤ 0.030 [0.76]                 | 0.060 [1.5]                          | + 0.030 [0.76]<br>– 0.010 [0.25] | 45°              | + 10°<br>– 5° <sup>d</sup> |
| FCAW               |                                    |                                |                                      |                                  | 60°              | + 10°                      |
| SAW                |                                    |                                |                                      |                                  |                  | – 5° <sup>e</sup>          |

- <sup>a</sup> Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.
- <sup>b</sup> Non-keyhole mode only.
- <sup>c</sup> Back-gouging to sound metal is required before welding second side.
- <sup>d</sup> Applicable to ferrous, heat resistant alloys, and magnesium alloys.
- <sup>e</sup> Applicable to aluminum and titanium alloys.

Figure A.1(g)—Double-V-Groove Weld Joints





| Weld Process              | Base Metal Thickness [T] (in [mm]) | Max Root Opening [R] (in [mm]) | Root Face [f] (in [mm]) <sup>a</sup>      | Groove Angle [α] | Groove Radius [r] (in [mm])                |
|---------------------------|------------------------------------|--------------------------------|-------------------------------------------|------------------|--------------------------------------------|
| GTAW <sup>b</sup>         | 0.501–1.400 [13.1–36]              | ≤ 0.030 [0.76]                 | 0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |
|                           | ≥ 1.400 [36]                       | ≤ 0.030 [0.76]                 | 0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |
| PAW <sup>c,b</sup>        | 0.501–1.400 [13.1–36]              | ≤ 0.030 [0.76]                 | 0.040 [1.0] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |
|                           | ≥ 1.400 [36]                       | ≤ 0.030 [0.76]                 | 0.060 [1.5] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |
| GMAW <sup>b</sup><br>FCAW | 0.501–1.400 [13.1–36]              | ≤ 0.030 [0.76]                 | 0.080 [2.0] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |
| SAW                       | ≥ 1.400 [36]                       | ≤ 0.030 [0.76]                 | 0.120 [3.0] + 0.030 [0.76] – 0.010 [0.25] | 30° +10° –5°     | 0.380 [9.65] + 0.030 [0.76] – 0.010 [0.25] |

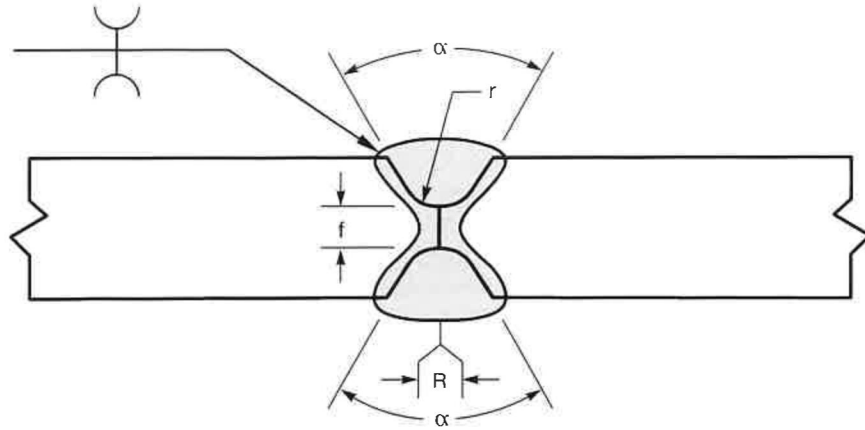
<sup>a</sup> Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

<sup>b</sup> Back-gouging to sound metal is required before welding second side.

<sup>c</sup> Non-keyhole mode only.

**Figure A.1(h)—Double-J-Groove Weld Joints**

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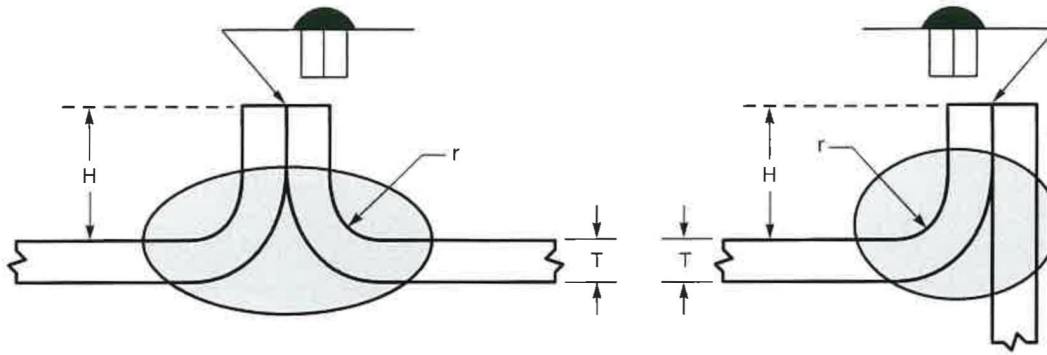
| Weld Process                     | Base Metal Thickness [T] (in [mm]) | Max Root Opening [R] (in [mm]) | Root Face [f] (in [mm]) <sup>a</sup> |                                | Groove Angle [α] |             | Groove Radius (r) (in [mm]) |                                |
|----------------------------------|------------------------------------|--------------------------------|--------------------------------------|--------------------------------|------------------|-------------|-----------------------------|--------------------------------|
| GTAW <sup>b</sup>                | 0.501–0.800 [13.1–20]              | ≤0.030 [0.76]                  | 0.040 [1.0]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |
|                                  | >0.800 [>20]                       | ≤0.030 [0.76]                  | 0.060 [1.5]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |
| PAW <sup>b,c</sup>               | 0.501–0.800 [13.1–20]              | ≤0.030 [0.76]                  | 0.040 [1.0]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |
|                                  | >0.800 [>20]                       | ≤0.030 [0.76]                  | 0.060 [1.5]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |
| GMAW <sup>c</sup><br>FCAW<br>SAW | 0.501–0.800 [13.1–20]              | ≤0.030 [0.76]                  | 0.080 [2.0]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |
|                                  | >0.800 [>20]                       | ≤0.030 [0.76]                  | 0.120 [3.0]                          | +0.030 [0.76]<br>–0.010 [0.25] | 20°              | +10°<br>–5° | 0.250 [6.35]                | +0.030 [0.76]<br>–0.010 [0.25] |

<sup>a</sup> Applies to complete joint penetration groove welds only. Root face height for partial joint penetration groove welds is governed by joint strength requirements.

<sup>b</sup> Back-gouging to sound metal is required before welding second side.

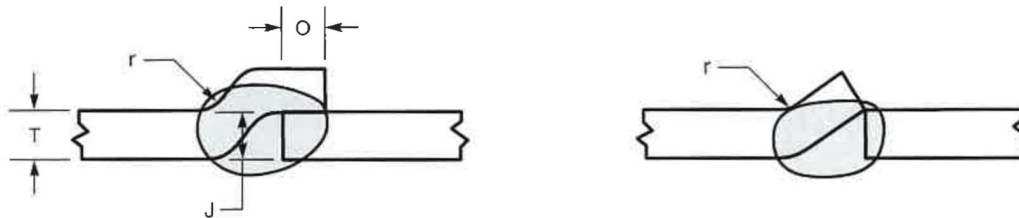
<sup>c</sup> Non-keyhole mode only.

**Figure A.1(i)—Double-U-Groove Weld Joints**



| Thickness [T] in [mm]  | Bend Radius [r] Max (in [mm]) | Flange Height [H] (in [mm]) |
|------------------------|-------------------------------|-----------------------------|
| 0.016—0.032 [0.4—0.8]  | 0.04 [1.0]                    | 0.08—0.12 [2.0—3.0]         |
| 0.033—0.062 [0.81—1.5] | 0.06 [1.5]                    | 0.10—0.16 [2.5—4.1]         |
| 0.063—0.100 [1.51—2.5] | 2T                            | 0.12—0.20 [3.1—5.1]         |

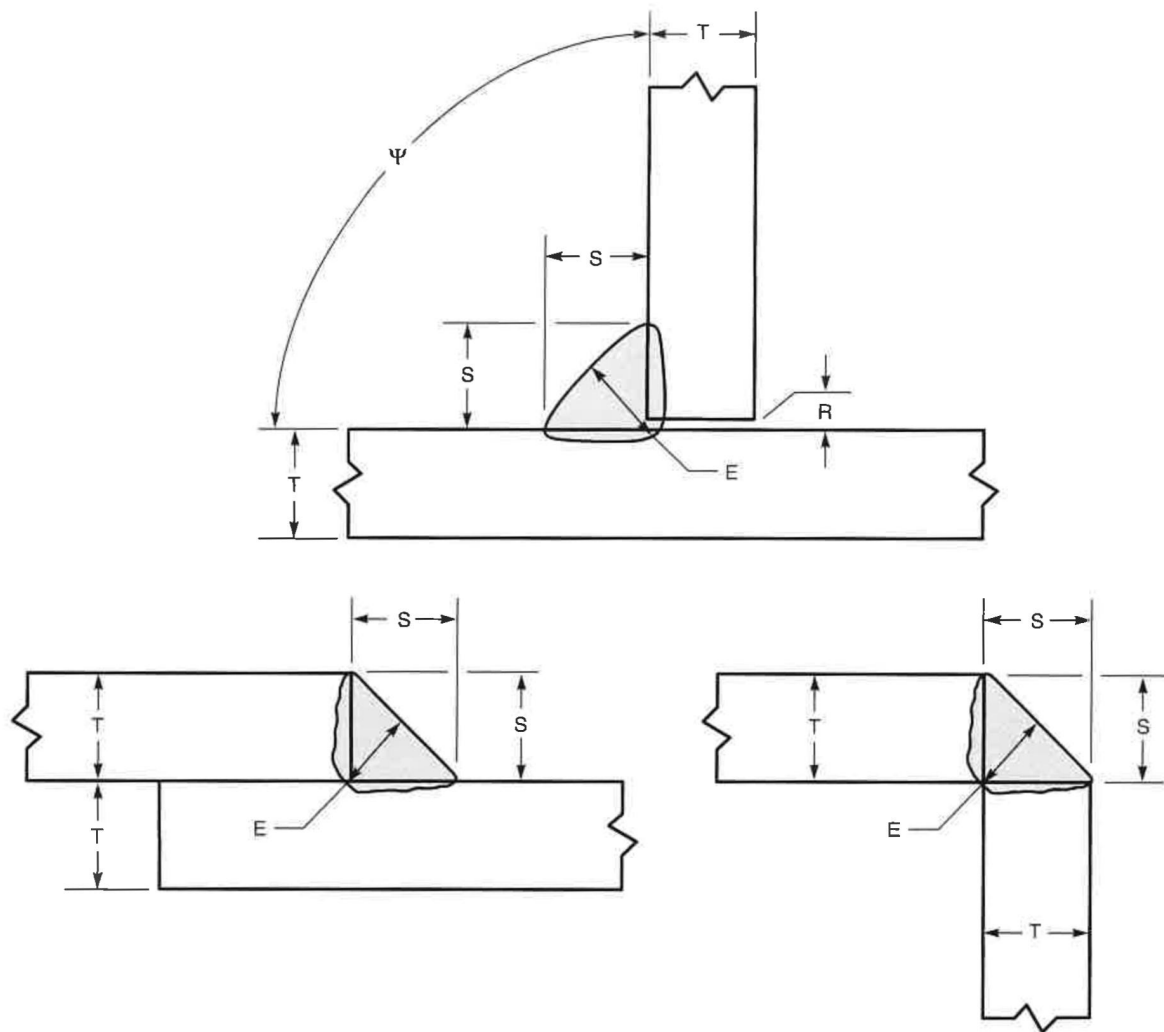
Figure A.2 (a)—Flanged Joints



| Base Metal                 | Base Metal Thickness [T] (in [mm]) | Bend Radius [r] (in [mm]) | Joggle [J] (in [mm])             | Overlap [O] (in [mm])   |
|----------------------------|------------------------------------|---------------------------|----------------------------------|-------------------------|
| Commercially Pure Titanium | 0.020—0.040 [0.5—1.0]              | 0.04 [1.0] max.           | T +0.005 [0.13]<br>-0.000 [0.00] | 0.032—0.060 [0.81—1.52] |
| Stainless Steel            | 0.020—0.063 [0.5—1.5]              | 0.04 [1.0] max.           | T +0.005 [0.13]<br>-0.000 [0.00] | 0.032—0.090 [0.81—2.29] |
| Nickel                     | 0.020—0.063 [0.5—1.5]              | 0.06 [1.5] max.           | T +0.005 [0.13]<br>-0.000 [0.00] | 0.032—0.090 [0.81—2.29] |

Figure A.2(b)—Flanged Parallel Joints (Nonstandard)

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**Legend:**

R = Root gap  
T = Thickness of thinnest member  
S = Minimum weld size  
E = Minimum effective throat  
 $\Psi$  = Skew angle  
 $E_{min} = 0.707T \times \text{factor}^{(1)}$

**Notes:**

1. For corner or lap joints where full throat thickness is required:  $S_{min} = T_{min}$ , where T equals thickness of thinner member.
2. For fillet weld size factor see Table A.1.

**Figure A.3—Fillet Weld Details**



**Table A.1  
Equivalent Fillet Weld Size for Skewed T-Joints**

| <b>Dihedral<br/>Angle [Y]</b> | <b>Comparable Fillet Weld<br/>Size for Same Strength</b> |
|-------------------------------|----------------------------------------------------------|
| 60                            | 0.71                                                     |
| 65                            | 0.76                                                     |
| 70                            | 0.81                                                     |
| 75                            | 0.86                                                     |
| 80                            | 0.91                                                     |
| 85                            | 0.96                                                     |
| 90                            | 1.00                                                     |
| 95                            | 1.03                                                     |
| 100                           | 1.08                                                     |
| 105                           | 1.12                                                     |
| 110                           | 1.16                                                     |
| 115                           | 1.19                                                     |
| 120                           | 1.23                                                     |
| 125                           | 1.25                                                     |
| 130                           | 1.28                                                     |
| 135                           | 1.31                                                     |

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## Annex B (Normative) Bend Testing Criteria

This annex is part of this standard and includes mandatory elements for use with this standard.

### B1. Scope.

This annex covers the bend testing of groove welds and bend testing of fillet welds. It provides the requirements for bend test specimen preparation, test parameters, bend radius requirements, and acceptance criteria. This annex shall be used when bend testing is the method to accept either a welding procedure, welder, or operator qualification.

### B2. Criteria for Bend Testing.

Bend testing may be used as an alternative to radiographic examination if the following conditions are met:

- (1) The members of the test weld differ in thickness by less than 10 % of the thicker member.
- (2) For tube welds, the outside diameter is equal to or more than 2 in [50 mm] in or the wall thickness is equal to or more than 0.250 in [6.35 mm].
- (3) Alloy is not included in Table B.1.

### B3. Bend Testing.

Perform bend testing using guided bend test fixtures (See Figures B.2, B.3, and B.4). The groove weld in sheet bend radius requirements are in Tables B.2 and B.2M. The bend test requirements for groove welds in tubes are in Table B.3.

### B4. Acceptance Criteria.

**B4.1 Groove Welds.** Bend specimens from groove welds shall have no open discontinuity exceeding base metal thickness (T) or 1/8 in [3.2 mm] whichever is the lesser, measured in any direction on the convex surface of the specimen after bending. Cracks occurring on the corners of the specimen during bending shall not be rejected, unless there is evidence that they result from slag inclusions or other discontinuities.

**B4.2 Fillet Welds.** Bend specimens for fillet weld bend-break tests shall be bent with the weld root in tension until the specimen either fractures or until it is bent flat upon itself. The specimen shall be accepted if:

- (1) The specimen does not fracture; or
- (2) If the fillet fractures, the fractured surface shall exhibit no cracks or incomplete root fusion and no inclusion or porosity in the fracture surface exceeding 3/32 in [2.4 mm] in its greatest dimension; or
- (3) The sum of the greatest dimension of all inclusions and porosity in the specimen length does not exceed 3/8 in [9.5 mm].

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**Table B.1  
Base Metals for Which Bend Testing is Not Applicable**

| Base Metal Group                                              | Unified Number                                                     | Common Description                                                                                                                                       |
|---------------------------------------------------------------|--------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|
| IA<br>Carbon and Alloy Steels                                 | K91122<br>K91283<br>K91313<br>K91472<br>K92810                     | 9Ni-4Co steel<br><br><br><br>18Ni maraging steel                                                                                                         |
| IB<br>Heat Treatable Alloy Steels                             | All                                                                |                                                                                                                                                          |
| IIA<br>Stainless Steels                                       | S63198<br>S63199<br>R30155<br>R30590<br>S41800<br>S42000<br>S42200 | 19-9 DL<br>19-9 DX<br>N155<br>S590<br>Greek Ascology<br>420<br>422                                                                                       |
| IIB<br>Precipitation Hardenable Stainless Steels              | All                                                                |                                                                                                                                                          |
| IIIB<br>Precipitation Hardening Nickel and Nickel Base Alloys | All                                                                |                                                                                                                                                          |
| IV<br>Aluminum Alloys                                         | A03560<br>A92014<br>A92219                                         | 356<br>2014<br>2219                                                                                                                                      |
| V<br>Magnesium Alloys                                         | All                                                                |                                                                                                                                                          |
| VI<br>Titanium Alloys                                         | R54620<br>R56210<br>R56260<br>R56620<br>R58640<br>NA<br>NA         | Ti-6Al-2Sn-4Zr-2Mo<br>Ti-6Al-2Cb-1Ta-1Mo<br>Ti-6Al-2Sn-4Zr-6Mo<br>Ti-6Al-6V-2Sn<br>Ti-3Al-8V-6Cr-4Mo-4Zr<br>Ti-6Al-2Sn-2Zr-2Cr-2Mo<br>Ti-15V-3Cr-3Mo-3Sn |
| VII<br>Cobalt Base Alloys                                     | All                                                                |                                                                                                                                                          |



**Table B.2  
Bend Specimen Thickness and Bend Radius (in)**

| Bend<br>Radius, A<br>in <sup>b</sup> | Bend Specimen Thickness <sup>a</sup> |                  |                            |             |                            |             |
|--------------------------------------|--------------------------------------|------------------|----------------------------|-------------|----------------------------|-------------|
|                                      | Unified Number (UNS)                 |                  |                            |             |                            |             |
|                                      | R54520<br>R54810<br>R56320<br>R56400 | A96061<br>A96063 | R50400<br>R50550<br>R52400 | R50250      | A95083<br>A95086<br>A95456 | Other       |
|                                      | F = 12 <sup>c</sup>                  | F = 8            | F = 5                      | F = 4       | F = 3                      | F = 2       |
|                                      | ≥ <                                  | ≥ <              | ≥ <                        | ≥ <         | ≥ <                        | ≥ <         |
| 0.070                                |                                      |                  |                            |             |                            | 0.031 0.035 |
| 0.079                                |                                      |                  |                            |             |                            | 0.035 0.039 |
| 0.088                                |                                      |                  |                            |             |                            | 0.039 0.044 |
| 0.099                                |                                      |                  |                            |             | 0.029 0.033                | 0.044 0.050 |
| 0.111                                |                                      |                  |                            |             | 0.033 0.037                | 0.050 0.056 |
| 0.125                                |                                      |                  |                            |             | 0.037 0.042                | 0.056 0.062 |
| 0.140                                |                                      |                  |                            | 0.031 0.035 | 0.042 0.047                | 0.062 0.070 |
| 0.157                                |                                      |                  |                            | 0.035 0.039 | 0.047 0.052                | 0.070 0.078 |
| 0.176                                |                                      |                  | 0.031 0.035                | 0.039 0.044 | 0.052 0.059                | 0.078 0.088 |
| 0.198                                |                                      |                  | 0.035 0.040                | 0.044 0.049 | 0.059 0.066                | 0.088 0.099 |
| 0.222                                |                                      |                  | 0.040 0.044                | 0.049 0.055 | 0.066 0.074                | 0.099 0.111 |
| 0.249                                |                                      |                  | 0.044 0.050                | 0.055 0.062 | 0.074 0.083                | 0.111 0.124 |
| 0.279                                |                                      | 0.031 0.035      | 0.050 0.056                | 0.062 0.070 | 0.083 0.093                | 0.124 0.140 |
| 0.313                                |                                      | 0.035 0.039      | 0.056 0.063                | 0.070 0.078 | 0.093 0.104                | 0.140 0.157 |
| 0.351                                |                                      | 0.039 0.044      | 0.063 0.070                | 0.078 0.088 | 0.104 0.117                | 0.157 0.176 |
| 0.394                                | 0.029 0.033                          | 0.044 0.049      | 0.070 0.079                | 0.088 0.099 | 0.117 0.131                | 0.176 0.197 |
| 0.442                                | 0.033 0.037                          | 0.049 0.055      | 0.079 0.088                | 0.099 0.111 | 0.131 0.147                | 0.197 0.221 |
| 0.496                                | 0.037 0.041                          | 0.055 0.062      | 0.088 0.099                | 0.111 0.124 | 0.147 0.165                | 0.221 0.248 |
| 0.557                                | 0.041 0.046                          | 0.062 0.070      | 0.099 0.111                | 0.124 0.139 | 0.165 0.186                | 0.248 0.279 |
| 0.625                                | 0.046 0.052                          | 0.070 0.078      | 0.111 0.125                | 0.139 0.156 | 0.186 0.208                | 0.279 0.312 |
| 0.701                                | 0.052 0.058                          | 0.078 0.088      | 0.125 0.140                | 0.156 0.175 | 0.208 0.234                | 0.312 0.351 |
| 0.787                                | 0.058 0.066                          | 0.088 0.098      | 0.140 0.157                | 0.175 0.197 | 0.234 0.262                | 0.351 0.393 |
| 0.883                                | 0.066 0.074                          | 0.098 0.110      | 0.157 0.177                | 0.197 0.221 | 0.262 0.294                |             |
| 0.991                                | 0.074 0.083                          | 0.110 0.124      | 0.177 0.198                | 0.221 0.248 | 0.294 0.330                |             |
| 1.111                                | 0.083 0.093                          | 0.124 0.139      | 0.198 0.222                | 0.248 0.278 | 0.330 0.370                |             |
| 1.247                                | 0.093 0.104                          | 0.139 0.156      | 0.222 0.249                | 0.278 0.312 | 0.370 0.416                |             |
| 1.399                                | 0.104 0.117                          | 0.156 0.175      | 0.249 0.280                | 0.312 0.350 |                            |             |
| 1.570                                | 0.117 0.131                          | 0.175 0.196      | 0.280 0.314                | 0.350 0.392 |                            |             |
| 1.761                                | 0.131 0.147                          | 0.196 0.220      | 0.314 0.352                |             |                            |             |
| 1.976                                | 0.147 0.165                          | 0.220 0.247      | 0.352 0.395                |             |                            |             |
| 2.218                                | 0.165 0.185                          | 0.247 0.277      |                            |             |                            |             |
| 2.488                                | 0.185 0.207                          | 0.277 0.311      |                            |             |                            |             |
| 2.872                                | 0.207 0.233                          | 0.311 0.349      |                            |             |                            |             |
| 3.132                                | 0.233 0.261                          | 0.349 0.392      |                            |             |                            |             |
| 3.515                                | 0.261 0.293                          |                  |                            |             |                            |             |
| 3.943                                | 0.293 0.329                          |                  |                            |             |                            |             |
| 4.425                                | 0.329 0.369                          |                  |                            |             |                            |             |
| 4.965                                | 0.369 0.414                          |                  |                            |             |                            |             |

<sup>a</sup> The body of the table contains the bend specimen thickness ( $T_b$ ) in inches.

<sup>b</sup> The tolerance on bend radius A is  $\pm 0.001$  in or  $\pm 1\%$ , whichever is the larger.

<sup>c</sup> F = Bend factor

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**Table B.2M**  
**Bend Specimen Thickness and Bend Radius (mm)**

| Bend<br>Radius, A<br>mm <sup>b</sup> | Bend Specimen Thickness <sup>a</sup> |                  |                            |           |                            |           |
|--------------------------------------|--------------------------------------|------------------|----------------------------|-----------|----------------------------|-----------|
|                                      | Unified Number (UNS)                 |                  |                            |           |                            |           |
|                                      | R54520<br>R54810<br>R56320<br>R56400 | A96061<br>A96063 | R50400<br>R50550<br>R52400 | R50250    | A95083<br>A95086<br>A95456 | Other     |
|                                      | F = 12 <sup>c</sup>                  | F = 8            | F = 5                      | F = 4     | F = 3                      | F = 2     |
|                                      | ≥ <                                  | ≥ <              | ≥ <                        | ≥ <       | ≥ <                        | ≥ <       |
| 1.78                                 |                                      |                  |                            |           |                            | 0.79 0.89 |
| 2.01                                 |                                      |                  |                            |           |                            | 0.89 0.99 |
| 2.24                                 |                                      |                  |                            |           |                            | 0.99 1.12 |
| 2.51                                 |                                      |                  |                            |           | 0.74 0.84                  | 1.12 1.27 |
| 2.82                                 |                                      |                  |                            |           | 0.84 0.94                  | 1.27 1.42 |
| 3.18                                 |                                      |                  |                            |           | 0.94 1.07                  | 1.42 1.57 |
| 3.56                                 |                                      |                  |                            | 0.79 0.89 | 1.07 1.19                  | 1.57 1.78 |
| 3.99                                 |                                      |                  |                            | 0.89 0.99 | 1.19 1.32                  | 1.78 1.98 |
| 4.47                                 |                                      |                  | 0.79 0.89                  | 0.99 1.12 | 1.32 1.50                  | 1.98 2.24 |
| 5.03                                 |                                      |                  | 0.89 1.02                  | 1.12 1.24 | 1.50 1.68                  | 2.24 2.51 |
| 5.64                                 |                                      |                  | 1.02 1.12                  | 1.24 1.40 | 1.68 1.88                  | 2.51 2.82 |
| 6.32                                 |                                      |                  | 1.12 1.27                  | 1.40 1.57 | 1.88 2.11                  | 2.82 3.15 |
| 7.09                                 |                                      | 0.79 0.89        | 1.27 1.42                  | 1.57 1.78 | 2.11 2.36                  | 3.15 3.56 |
| 7.95                                 |                                      | 0.89 0.99        | 1.42 1.60                  | 1.78 1.98 | 2.36 2.64                  | 3.56 3.99 |
| 8.92                                 |                                      | 0.99 1.12        | 1.60 1.78                  | 1.98 2.24 | 2.64 2.97                  | 3.99 4.47 |
| 10.01                                | 0.74 0.84                            | 1.12 1.24        | 1.78 2.01                  | 2.24 2.51 | 2.97 3.33                  | 4.47 5.00 |
| 11.23                                | 0.84 0.94                            | 1.24 1.40        | 2.01 2.24                  | 2.51 2.82 | 3.33 3.73                  | 5.00 5.61 |
| 12.60                                | 0.94 1.04                            | 1.40 1.57        | 2.24 2.51                  | 2.82 3.15 | 3.73 4.19                  | 5.61 6.30 |
| 14.15                                | 1.04 1.17                            | 1.57 1.78        | 2.51 2.82                  | 3.15 3.53 | 4.19 4.72                  | 6.30 7.09 |
| 15.88                                | 1.17 1.32                            | 1.78 1.98        | 2.82 3.18                  | 3.53 3.96 | 4.72 5.28                  | 7.09 7.92 |
| 17.01                                | 1.32 1.47                            | 1.98 2.24        | 3.18 3.56                  | 3.96 4.45 | 5.28 5.94                  | 7.92 8.92 |
| 20.00                                | 1.47 1.68                            | 2.24 2.49        | 3.56 3.99                  | 4.45 5.00 | 5.94 6.65                  | 8.92 9.98 |
| 22.43                                | 1.68 1.88                            | 2.49 2.79        | 3.99 4.50                  | 5.00 5.61 | 6.65 7.47                  |           |
| 25.17                                | 1.88 2.11                            | 2.79 3.15        | 4.50 5.03                  | 5.61 6.30 | 7.47 8.38                  |           |
| 28.22                                | 2.11 2.36                            | 3.15 3.53        | 5.03 5.64                  | 6.30 7.06 | 8.38 9.40                  |           |
| 31.67                                | 2.36 2.64                            | 3.53 3.96        | 5.64 6.32                  | 7.06 7.92 | 9.40 10.57                 |           |
| 35.53                                | 2.64 2.97                            | 3.96 4.45        | 6.32 7.11                  | 7.92 8.89 |                            |           |
| 39.88                                | 2.97 3.33                            | 4.45 4.98        | 7.11 7.98                  | 8.89 9.96 |                            |           |
| 44.73                                | 3.33 3.73                            | 4.98 5.59        | 7.98 8.94                  |           |                            |           |
| 50.19                                | 3.73 4.19                            | 5.59 6.27        | 8.94 10.03                 |           |                            |           |
| 56.34                                | 4.19 4.70                            | 6.27 7.04        |                            |           |                            |           |
| 63.20                                | 4.70 5.26                            | 7.04 7.90        |                            |           |                            |           |
| 72.95                                | 5.26 5.92                            | 7.90 8.86        |                            |           |                            |           |
| 79.96                                | 5.92 6.63                            | 8.86 9.96        |                            |           |                            |           |
| 89.28                                | 6.63 7.44                            |                  |                            |           |                            |           |
| 100.15                               | 7.44 8.36                            |                  |                            |           |                            |           |
| 112.40                               | 8.36 9.37                            |                  |                            |           |                            |           |
| 126.11                               | 9.37 10.52                           |                  |                            |           |                            |           |

<sup>a</sup> The body of the table contains the bend specimen thickness (T<sub>1</sub>) in millimeters.

<sup>b</sup> The tolerance on bend radius A is ±0.03 mm or ±1%, whichever is the larger.

<sup>c</sup> F = Bend factor

**Table B.3  
Bend Specimens for Groove Welds in Tube (in)**

| Tube                |                      |                   | Bend Test Specimen                |                |          |          |       |
|---------------------|----------------------|-------------------|-----------------------------------|----------------|----------|----------|-------|
| Outside Diameter in | Wall Thickness T, in | Base Metal Number | Type Shown in Fig. B.1            | Dimensions, in |          |          |       |
|                     |                      |                   |                                   | T <sub>1</sub> |          | W        |       |
|                     |                      |                   |                                   | Min.           | Max.     | Min.     | Max.  |
| < 2                 | All                  | All               | Radiographic Examination Required |                |          |          |       |
| 2 – 5               | < 0.250              | All               | Radiographic Examination Required |                |          |          |       |
|                     | ≥ 0.250 – 0.375      | (Note a)          | TB-e and TB-f                     | 0.115          | 0.135    | 0.750    | 0.800 |
|                     |                      | All Others        | TB-e and TB-f                     | (Note b)       | (Note b) | 0.750    | 0.800 |
|                     | > 0.375 – 0.750      | (Note a)          | TB-e and TB-f or SB-g             | 0.115          | 0.135    | 0.750    | 0.800 |
|                     |                      |                   |                                   | 0.115          | 0.135    | T        | T     |
|                     |                      | All Others        | TB-e and TB-f or SB-g             | (Note c)       | (Note c) | 0.750    | 0.800 |
|                     |                      |                   |                                   | 0.350          | 0.400    | T        | T     |
|                     | > 0.750              | (Note a)          | SB-g                              | 0.115          | 0.135    | T        | T     |
|                     |                      | All Others        | SB-g                              | 0.350          | 0.400    | T        | T     |
|                     | < 0.250              | All               | Radiographic Inspection Required  |                |          |          |       |
| > 5                 | ≥ 0.250 – 0.375      | (Note a)          | TB-e and TB-f                     | 0.115          | 0.135    | 1.50     | 1.55  |
|                     |                      | All Others        | TB-e and TB-f                     | (Note b)       | (Note b) | 1.50     | 1.55  |
|                     | > 0.375 – 0.750      | (Note a)          | TB-e and TB-f or SB-g             | 0.115          | 0.135    | 1.50     | 1.55  |
|                     |                      |                   |                                   | 0.115          | 0.135    | T        | T     |
|                     |                      | All Others        | TB-e and TB-f or SB-g             | (Note c)       | (Note c) | 1.50     | 1.55  |
|                     |                      |                   |                                   | 0.350          | 0.400    | T        | T     |
|                     | > 0.750              | (Note a)          | SB-g                              | 0.115          | 0.135    | (Note d) | T     |
|                     |                      | All Others        | SB-g                              | 0.350          | 0.400    | (Note d) | T     |

<sup>a</sup> A96061 and A96063 of Base Metal Group IV.

<sup>b</sup> The maximum T<sub>1</sub> is the thickness resulting from dressing of the curved surface to plane. The minimum T<sub>1</sub> is 0.9 times the maximum.

<sup>c</sup> The maximum T<sub>1</sub> is the thickness resulting from dressing the curved surface to a plane, or 0.400 in, whichever is lesser. In the first case, the minimum T<sub>1</sub> is 0.9 times the maximum. In the second case, the minimum T<sub>1</sub> is 0.350 in.

<sup>d</sup> For wall thicknesses of >0.750 to 1.50 in, W is equal to T. For wall thicknesses of >1.50 in, specimens may be cut into approximately equal strips between 0.75 and 1.50 in wide for testing, or the specimens may be bent at full width.

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**Table B.3M  
Bend Specimens for Groove Welds in Tube (mm)**

| Tube                   |                         |                      | Bend Test Specimen                |                |          |          |      |
|------------------------|-------------------------|----------------------|-----------------------------------|----------------|----------|----------|------|
| Outside Diameter<br>mm | Wall Thickness T,<br>mm | Base Metal<br>Number | Type Shown in<br>Fig. B.1         | Dimensions, mm |          |          |      |
|                        |                         |                      |                                   | T <sub>1</sub> |          | W        |      |
|                        |                         |                      |                                   | Min.           | Max.     | Min.     | Max. |
| 50                     | All                     | All                  | Radiographic Examination Required |                |          |          |      |
| 50–127                 | < 6.4                   | All                  | Radiographic Examination Required |                |          |          |      |
|                        | ≥6.4 – 9.5              | (Note a)             | TB-e and TB-f                     | 2.9            | 3.4      | 19.1     | 20.3 |
|                        |                         | All Others           | TB-e and TB-f                     | (Note b)       | (Note b) | 19.1     | 20.3 |
|                        | > 9.5–19                | (Note a)             | TB-e and TB-f<br>or<br>SB-g       | 2.9            | 3.4      | 19.1     | 20.3 |
|                        |                         |                      |                                   | 2.9            | 3.4      | T        | T    |
|                        |                         | All Others           | TB-e and TB-f<br>or<br>SB-g       | (Note c)       | (Note c) | 19.1     | 20.3 |
|                        |                         |                      |                                   | 8.9            | 10       | T        | T    |
|                        | > 19                    | (Note a)             | SB-g                              | 2.9            | 3.4      | T        | T    |
|                        |                         | All Others           | SB-g                              | 8.9            | 10.2     | T        | T    |
|                        | < 6.4                   | All                  | Radiographic Examination Required |                |          |          |      |
| >127                   | ≥6.4–9.5                | (Note a)             | TB-e and TB-f                     | 2.9            | 3.4      | 38.1     | 39.4 |
|                        |                         | All Others           | TB-e and TB-f                     | (Note b)       | (Note b) | 38.1     | 39.4 |
|                        | > 9.5–19                | (Note a)             | TB-e and TB-f<br>or<br>SB-g       | 2.9            | 3.4      | 38.1     | 39.4 |
|                        |                         |                      |                                   | 2.9            | 3.4      | T        | T    |
|                        |                         | All Others           | TB-e and TB-f<br>or<br>SB-g       | (Note c)       | (Note c) | 38.1     | 39.4 |
|                        |                         |                      |                                   | 8.9            | 10.2     | T        | T    |
|                        | > 19                    | (Note a)             | SB-g                              | 2.9            | 3.4      | (Note d) | T    |
|                        |                         | All Others           | SB-g                              | 8.9            | 10.2     | (Note d) | T    |

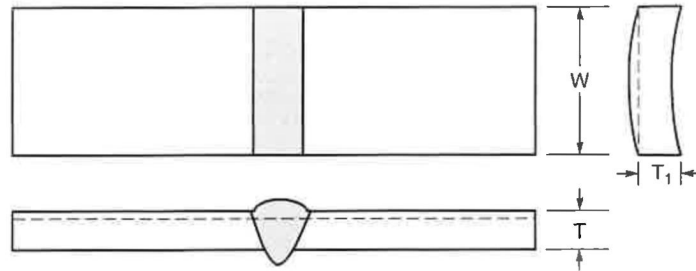
<sup>a</sup> A96061 and A96063 of Base Metal Group IV.

<sup>b</sup> The maximum T<sub>1</sub> is the thickness resulting from dressing of the curved surface to plane. The minimum T<sub>1</sub> is 0.9 times the maximum.

<sup>c</sup> The maximum T<sub>1</sub> is the thickness resulting from dressing the curved surface to a plane, or 10.16 mm, whichever is lesser. In the first case, the minimum T<sub>1</sub> is 0.9 times the maximum. In the second case, the minimum T<sub>1</sub> is 8.89 mm.

<sup>d</sup> For wall thicknesses of >19.05 to 38.1 mm, W is equal to T. For wall thicknesses of >38.1 mm, specimens may be cut into approximately equal strips between 19.1 to 38.1 mm wide for testing, or the specimens may be bent at full width.

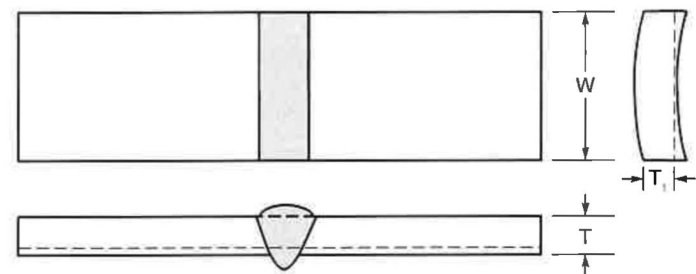




**TB**

Requirement: The thickness of the transverse root bend specimen is measured at the specimen edge.

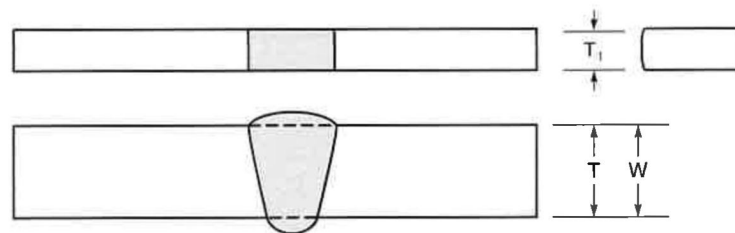
**(A) TRANSVERSE ROOT BEND**



**TB**

Requirement: The thickness of the transverse face bend specimen is measured at the specimen center.

**(B) TRANSVERSE FACE BEND**

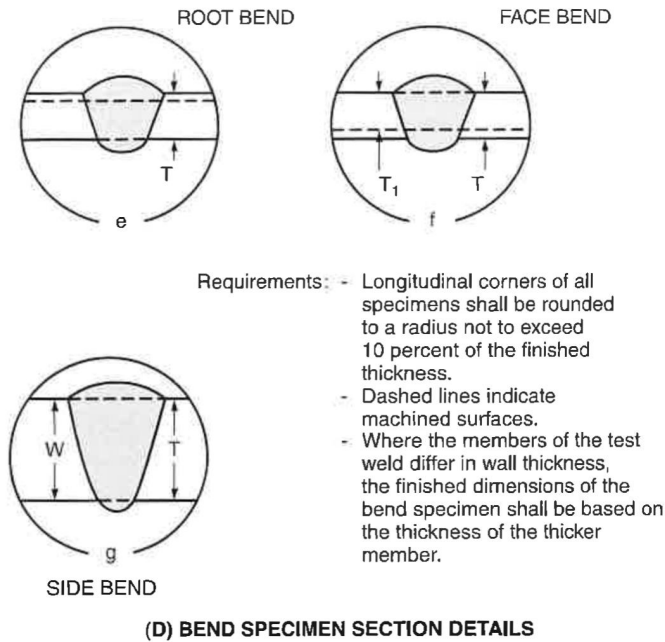


**SB**

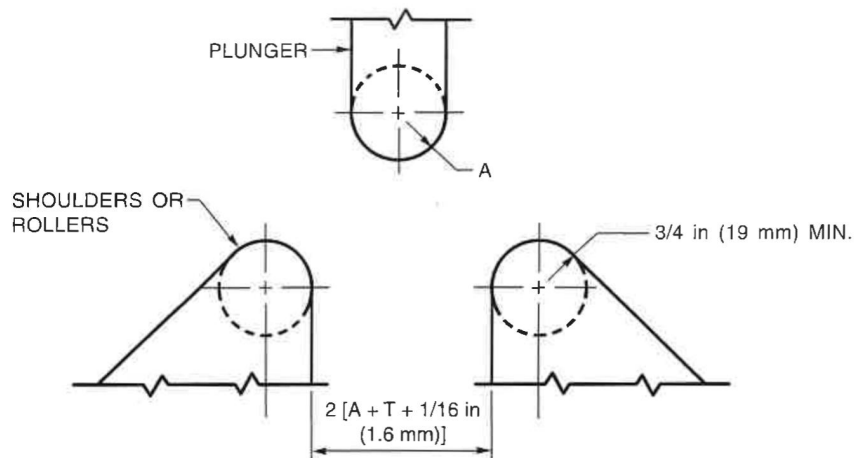
**(C) SIDE BEND**

**Figure B.1—Bend Specimens in Groove Welded Tube**

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**Figure B.1 (Continued)—Bend Specimens in Groove Welded Tube**



T = SPECIMEN THICKNESS

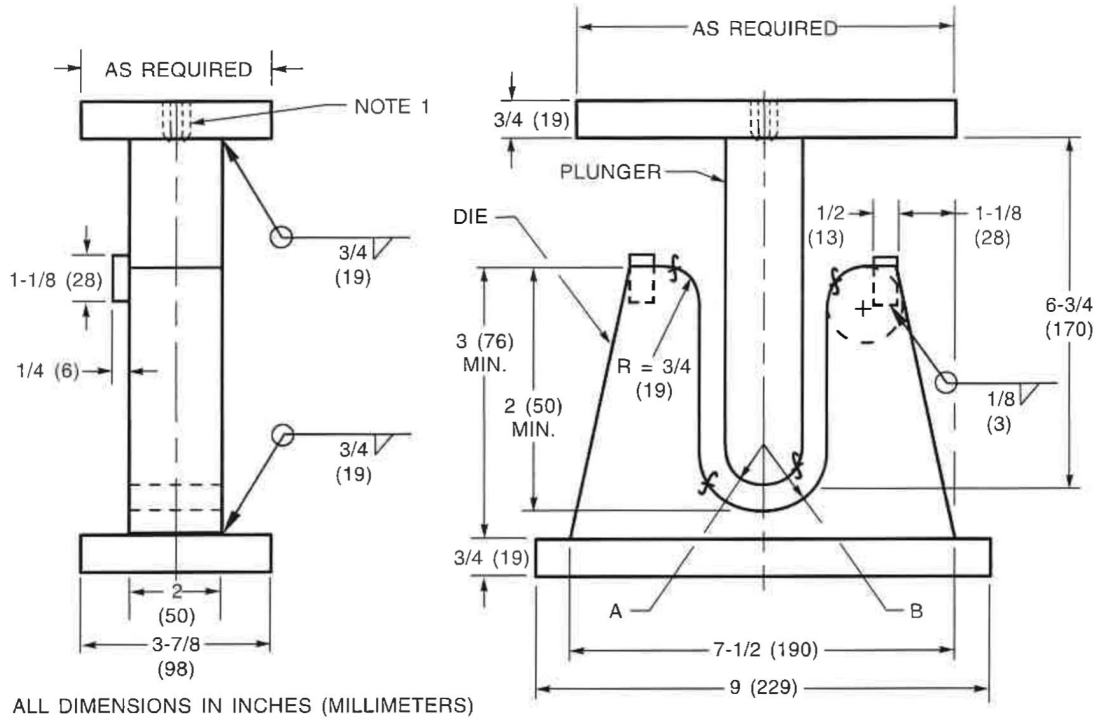
Notes:

1. Either hardened and greased shoulders or hardened rollers free to rotate should be used.
2. The shoulder or rollers shall have a minimum bearing length of 2 in (50 mm) for placement of the specimen.
3. The shoulders or rollers shall be high enough above the bottom of the fixture so that the specimen will clear the shoulders or rollers when the plunger is in the low position.
4. The plunger shall be fitted with an appropriate base and provision for attachment to the testing machine and shall be designed to minimize deflection or misalignment.
5. The shoulder or roller supports may be made adjustable in the horizontal direction so that specimens of various thickness may be tested in the same bend fixture.
6. The shoulder or roller supports shall be fitted to a base designed to maintain the shoulders or rollers centered and aligned with respect to the plunger, and minimize deflection or misalignment.
7. Plunger radius, A, shall be as specified in Table B.2M and B.2

Source: Adapted from AWS B4.0:2016-AMD1, *Standard Methods for Mechanical Testing of Welds*, Figure 6.1, American Welding Society.

**Figure B.2—Typical Bottom Ejecting Guided Bend Test Fixture**

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| Weld Symbol Conversions |               |
|-------------------------|---------------|
| US Customary (in)       | SI Units (mm) |
| 1/8                     | 3             |
| 3/4                     | 19            |

| Fixture Dimensions for 20% Elongation of Weld |                           |                       |
|-----------------------------------------------|---------------------------|-----------------------|
| Specimen Thickness, T in (mm)                 | Plunger Radius, A in (mm) | Die Radius, B in (mm) |
| 3/8 (10)                                      | 3/4 (19)                  | 1-3/16 (32)           |
| T                                             | 2T                        | A + T + 1/16 (1.6)    |

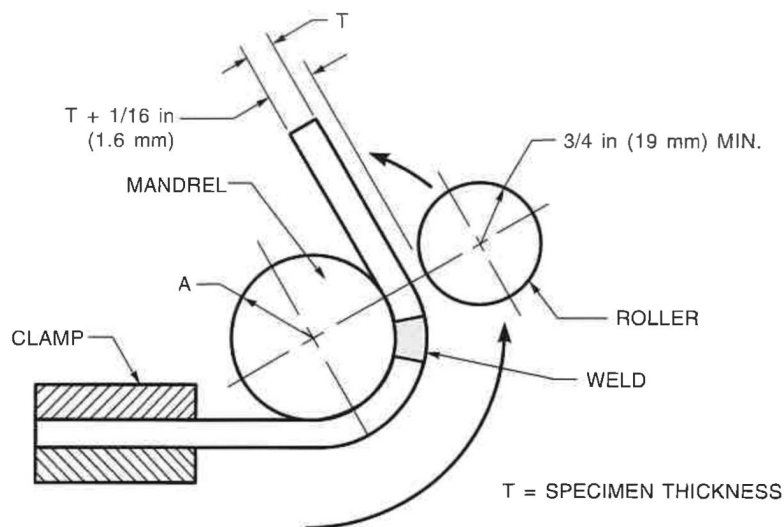
Notes:

1. Tapped hole of appropriate size, or other suitable means for attaching plunger to testing machine.
2. Either hardened and greased shoulders or hardened rollers free to rotate should be used in die.
3. The plunger and its base shall be designed to minimize deflection and misalignment.
4. The plunger shall force the specimen into the die until the specimen becomes U-shaped. The weld and heat-affected zones shall be centered and completely within the bent portion of the specimen after testing.
5. Plunger radius, A, shall be as specified in Table B.2M and B.2.
6. Weld sizes indicated are recommendations. The actual fillet weld size is the responsibility of the user to ensure rigidity and design adequacy.

Source: Adapted from AWS B4.0:2016-AMD1, *Standard Methods for Mechanical Testing of Welds*, Figure 6.2, American Welding Society.

**Figure B.3—Typical Bottom Guided Bend Test Fixture**





Notes:

1. Mandrel radius,  $A$ , shall be as specified in Table B.2M and B.2.
2. It is essential to have adequate rigidity so that the bend fixture will not deflect during testing. The specimen shall be firmly clamped on one end so that it does not slide during the bending operation.
3. Test specimens shall be removed from the bend fixture when the roller has traversed  $180^\circ$  from the starting point.

Source: Adapted from AWS B4.0:2016-AMD1, *Standard Methods for Mechanical Testing of Welds*, Figure 6.3, American Welding Society.

**Figure B.4—Typical Wraparound Guided Bend Test Fixture**

AWS D17.1/D17.1M:2024

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## Annex C (Informative)

### Informative References

This annex is not part of this standard but is included for informational purposes only.

#### American Welding Society Standards:

- AWS A5.9/A5.9M, *Specification for Bare Stainless Steel Welding Electrodes and Rods*
- AWS A5.10/A5.10M (ISO 18273) *Welding Consumables—Wire Electrodes, Wires and Rods for Welding Of Aluminum and Aluminum-Alloys—Classification*
- AWS A5.12M/A5.12 (ISO 6848 MOD), *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting*
- AWS A5.14/A5.14M, *Specification for Nickel and Nickel-Alloy Bare Welding Electrodes and Rods*
- AWS A5.16/A5.16M, (ISO 24034:2010 MOD) *Specification for Titanium and Titanium-Alloy Welding Electrodes and Rods*
- AWS A5.30/A5.30M, *Specification for Consumable Inserts*
- AWS A5.32M/A5.32, *Welding Consumables—Gases and Gas Mixtures for Fusion Welding and Allied Processes*
- AWS B4.0, *Standard Methods for Mechanical Testing of Welds*
- AWS B4.0M, *Standard Methods for Mechanical Testing of Welds*
- AWS C7.1M/C7.1, *Recommended Practices for Electron Beam Welding*
- AWS C7.2, *Recommended Practices for Laser Beam Welding, Cutting, and Allied Processes*
- AWS C7.3, *Process Specification for Electron Beam Welding*
- AWS C7.4 *Process Specification and Operator Qualification for Laser Beam Welding*
- AWS D1.1/D1.1M, *Structural Welding Code — Steel*
- AWS D1.2/D1.2M, *Structural Welding Code — Aluminum*
- AWS D1.3/D1.3M, *Structural Welding Code — Sheet Steel*
- AWS D1.4M/D1.4, *Structural Welding Code — Reinforcing Bar*
- AWS D1.5/D1.5M, *Bridge Welding Code*
- AWS D1.6/D1.6M, *Structural Welding Code — Stainless Steel*
- AWS D3.6M, *Specification for Underwater Welding*
- AWS D5.2, *Standard for Welded Steel — Elevated Tanks, Standpipes, and Reservoirs for Water Storage*, (American Waterworks Association (AWWA) Standard D100
- AWS D9.1M/D9.1, *Sheet Metal Welding Code*
- AWS D10.6/D10.6M, *Recommended Practices for Gas Tungsten Arc Welding Of Titanium Piping And Tubing*

AWS D17.1/D17.1M:2024

AWS D14.1/D14.1M, *Industrial and Mill Crane and Other Material Handling Equipment, Specification for Welding*

AWS D14.3/D14.3M, *Specification for Welding Earthmoving, Construction, and Agricultural Equipment*

AWS D14.4/D14.4M, *Specification for Welded Joints in Machinery and Equipment*

AWS D14.5/D14.5M, *Specification for Welding of Presses and Press Components*

AWS D14.6/D14.6M, *Rotating Elements for Equipment, Specification for Welding*

AWS D14.7/D14.7M, *Recommended Practice for Surfacing and Reconditioning of Industrial Mill Rolls*

AWS D14.8M (ISO/TR 17844:2004 IDT), *Standard Methods for the Avoidance of Cold Cracks*

AWS D15.1/D15.1M, *Railroad Welding Specification for Cars and Locomotives*

AWS G2.4/G2.4M, *Guide for the Fusion Welding Of Titanium and Titanium Alloys*

American Society for Mechanical Engineers (ASME) Codes for Pressure Piping:

ASME B31.1, *Power Piping*; and

ASME B31.3, *Process Piping*.

American National Standards Institute (ANSI) document:

ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*.

Federal and Military Specifications, Standards, and Handbooks:

A-A-59503, *Nitrogen Technical*

BB-O-925A, *Oxygen, Technical, Gas and Liquid*; BB-A-106, *Acetylene, Technical, Dissolved*

BB-C-101, *Carbon Dioxide, (CO<sub>2</sub>): Technical and U.S.P.*

BB-H-886, *Hydrogen*

BB-H-1168, *Helium, Technical*

MIL-DTL-18455, *Argon, Technical*

Code of Federal Regulations, Title 14, *Aeronautics and Space*

Compressed Gas Association (CGA) documents:

CGA G-1.1, *Commodity Specification for Acetylene*

CGA G-4.3, *Commodity Specification for Oxygen*

CGA G-5.3, *Commodity Specification for Hydrogen*

CGA G-6.2, *Commodity Specification for Carbon Dioxide*

CGA G-9.1, *Commodity Specification for Helium*

CGA G-10.1, *Commodity Specification for Nitrogen*

CGA G-11.1, *Commodity Specification for Argon*.

Society of Automotive Engineers (SAE) documents:

AMS4191, *Aluminum Alloy, Welding Wire 6.3Cu – 0.30Mn – 0.18Zr – 0.15Ti – 0.10V (2319)*

AMS4951, *Titanium Welding Wire Commercially Pure Environment Controlled Packaging*

AMS4953, *Titanium Alloy Welding Wire 5Al – 2.5Sn*

AMS4956, *Titanium Alloy Welding Wire 6Al – 4V, Extra Low Interstitial Environment Controlled Packaging*

AMS5804, *Steel, Corrosion and Heat Resistant, Welding Wire, 15Cr – 25.5Ni – 1.3Mo – 2.2Ti – 0.006B – 0.30V*



AMS5805, Steel, Corrosion and Heat Resistant, Welding Wire, 15Cr – 25.5Ni – 1.2Mo – 2.1Ti – 0.004B – 0.30V, Vacuum Induction Melted, Environment Controlled Packaging

AMS5812, Steel, Corrosion and Heat Resistant, Welding Wire 15Cr – 7.1Ni – 2.4Mo – 1.0Al Vacuum Induction Melted

AMS5824, Steel, Corrosion-Resistant, Welding Wire, 17Cr – 7.1Ni – 1.0Al

AMS5826, Steel, Corrosion and Heat-Resistant, Welding Wire, 15Cr – 5.1Ni – 0.30Cb(Nb) – 3.2Cu

AMS5832, Nickel Alloy, Corrosion and Heat Resistant, Welding Wire 52.5Ni – 19Cr – 3.0Mo – 5.1Cb(Nb) – 0.90Ti – 0.50Al – 18Fe Consumable Electrode or Vacuum Induction Melted

AMS5837, Nickel Alloy, Corrosion and Heat-Resistant, Welding Wire, 62Ni – 21.5Cr – 9.0Mo – 3.7Cb(Nb)

AMS5786, Nickel Alloy, Corrosion and Heat-Resistant, Welding Wire 62.5Ni – 5.0Cr – 24.5Mo – 5.5Fe

AMS2694, Aerospace Material Specification, In-process Welding of Castings

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## Annex D (Informative)

### Cross Referenced UNS Numbers to Proprietary Tradenames, ASTM, and AISI Designations

This annex is not part of this standard but is included for informational purposes only.

| Annex D (Informative)                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Material UNS numbers cross referenced to common name, material grade or alloy type () or to proprietary trade name[ ] |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Group (Table 5.6)                                                                                                     | Materials <sup>a</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| IB                                                                                                                    | Heat Treatable Alloy Steels: <ul style="list-style-type: none"> <li>• UNS G41300 (4130), G41350 (4135), G41400 (4140), G43400 (4340), G86300 (8630), K22925 (D6AC), K44220 (300M)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| IIA                                                                                                                   | Stainless Steels: <p>Austenitic Stainless Steels:</p> <ul style="list-style-type: none"> <li>• UNS N08330 (330), S20100 (201), S20200 (202), S21900 (21–6–9), S30100 (301), S30200 (302), S30300 (303), S30400 (304)</li> <li>• UNS S30800 (308), S30900 (309), S31000 (310), S31600 (316), S31700 (317), S32100 (321), S34700 (347), S34800 (348)</li> <li>• UNS S63198 (19–9DL), S63198 (19–9DX)</li> </ul> <p>Ferritic Stainless Steels:</p> <ul style="list-style-type: none"> <li>• UNS S40500 (405), S40900 (409), S42900 (429), S43000 (430), S43400 (434), S43600 (436), S43035 (439), S44100 (441)</li> <li>• UNS S44200 (442), S44600 (446)</li> </ul> <p>Martensitic Stainless Steels:</p> <ul style="list-style-type: none"> <li>• UNS S40300 (403), S41000 (410), S41400 (414), S41600 (416), S42000 (420), S42200 (422), S43100 (431), S44002 (440A)</li> <li>• UNS S44003 (440B), S44004 (440C)</li> </ul> |
| IIB                                                                                                                   | Precipitation Hardenable Stainless Steels: <ul style="list-style-type: none"> <li>• UNS S13800 (PH13–8Mo), S15500 (15–5PH), S15700 (PH15–7Mo), S17400 (17–4PH), S17700 (17–7PH), S35000 (AM–350)</li> <li>• UNS S35500 (AM–355), S45000 [Custom450], S45500 [Custom455], S66286 (A–286)</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| IIIA                                                                                                                  | Nickel and Nickel Base Alloys: <ul style="list-style-type: none"> <li>• UNS N02200 (Nickel 200), N02201 (Nickel 201), N04400 [Monel 400], N06002 [HastelloyX], N06007 [HastelloyG]</li> <li>• UNSN06455 [Hastelloy C4], N06600 [Inconel 600], N06625 [Inconel 625], N06975 [Hastelloy G2]</li> <li>• UNS N08020 [Carpenter 20Cb3], N08320 [Haynes 20 Mod.], N08800 [Incoloy 800], N08810 [Incoloy 800H]</li> <li>• UNS N08825 [Incoloy 825], N10001 [Hastelloy B], N10002 [Hastelloy C], N10003 [Hastelloy N]</li> <li>• UNS N10276 [Hastelloy C–276], N10665 [Hastelloy B2]</li> </ul>                                                                                                                                                                                                                                                                                                                                   |

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|      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| IIIB | <p>Precipitation Hardening Nickel and Nickel Base Alloys:</p> <ul style="list-style-type: none"> <li>• UNS N05500 [Monel K500], N06601 [Inconel 601], N07041 [Rene 41], N07718 [Inconel 718], N07750 [Inconel X750]</li> <li>• UNS N09706 [Inconel 706], N09901 [Incoloy 901]</li> <li>• UNS N19903 [Incoloy 903], N19907 [Incoloy 907], N19909 [Incoloy 909]</li> </ul>                                                                                                                                |
| IV   | <p>Non Heat Treatable Aluminum Alloys:</p> <ul style="list-style-type: none"> <li>• UNS A91060 (1060), A91100 (1100), A93003 (3003), A93004 (3004), A95052 (5052), A95083 (5083), A95086 (5086)</li> <li>• UNS A95154 (5154), A95254 (5254), A95454 (5454), A95456 (5456), A95652 (5652)</li> </ul> <p>Heat Treatable Aluminum Alloys:</p> <ul style="list-style-type: none"> <li>• UNS A03550 (355), A03560 (356), A03570 (357), A92014 (2014), A92219 (2219), A96061 (6061), A96063 (6063)</li> </ul> |
| V    | <p>Magnesium Alloys:</p> <ul style="list-style-type: none"> <li>• UNS M10100 (AM100A), M11311 (AZ31B), M11610 (AZ61A), M11800 (AZ80A), M11910 (AZ91A), M11920 (AZ92A)</li> <li>• UNS M12330 (EZ33A), M13210 (HM21A), M13310 (HK31A), M13312 (HM31A), M13320 (HZ32A), M14141 (LA141A)</li> <li>• UNS M16620 (ZH62A), M18220 (QE22A)</li> </ul>                                                                                                                                                           |
| VI   | <p>Titanium Alloys:</p> <ul style="list-style-type: none"> <li>• CP Titanium UNS R50250 (25), UNS R50400 (40), UNS R50550 (55)</li> <li>• UNS R54520 (Ti-5Al-2.5Sn), R54620 (Ti-6Al-2Sn-4Zr-2Mo), R54810 (Ti-8Al-1Mo-1V), R56210 (Ti-6Al-2Cu-1Ta-1Mo)</li> <li>• UNS R56260 (Ti-6Al-2Sn-4Zr-6Mo), R56320 (Ti-3Al-2.5V), R56400 (Ti-6Al-4V), R56620 (Ti-6Al-6V-2Sn)</li> <li>• UNS R58640 (Ti-3Al-8V-6Cr-4Mo-4Zr)</li> </ul>                                                                             |
| VII  | <p>Cobalt Base Alloys:</p> <ul style="list-style-type: none"> <li>• UNS R30006 [Stellite 6], R30106 [Stellite 6], R30021 [Stellite 21], R30023 [Stellite 23]</li> <li>• UNS R30027 [Stellite 27], R30030 [Stellite 30], R30031 [Stellite 31]</li> <li>• UNS R30188 [Haynes 188], R30605 [Carpenter L-605], R30816 [S-816]</li> </ul>                                                                                                                                                                    |

<sup>a</sup> Trade names may be provided for some common alloys with UNS number. These trade names are provided for information only, without regard for trademark status.



## Annex E (Informative) Commentary

This annex is not part of this standard but is included for informational purposes only.

### Foreword

All references to numbered paragraphs, tables, and figures, unless otherwise indicated, refer to subclauses, tables, or figures in AWS D17.1/D17.1M:2024, *Specification for Fusion Welding for Aerospace Applications*. Reference to subclauses, tables, or figures in this commentary is prefixed with the letter F. For example, Figure 5.1 is in AWS D17.1/D17.1M, while Clause F5.2 is in this commentary.

This commentary on AWS D17.1/D17.1M:2024 has been prepared to generate better understanding in the application of this specification in aircraft and aerospace welding.

Since the specification cannot contain background information or discuss the committee's intent, it is the function of this commentary to fill this need.

Suggestions for application, as well as clarification of specification requirements, are offered with specific emphasis on requirements that differ from the requirements given in MIL-STD-1595, or MIL-STD-2219, which provided a basis for the first edition of AWS D17.1:2001.

It should be recognized that the fundamental premise of this specification is to provide general stipulations and to leave sufficient latitude for the exercise of engineering judgment. Due to the diverse nature of the Aerospace industry, it is not possible to establish a single set of specification controls that are applicable to all design applications. This specification represents the collective experience of the committee, and while some provisions may seem overly conservative for some applications, they may be too liberal in others. All provisions are based on sound engineering practice. The Engineering Authority assumes responsibility for applying this specification in a given design situation and modifying the requirements to achieve the desired performance at reasonable cost without taking undue risk.

The committee, therefore, believes that a commentary is the most suitable means to provide clarification as well as proper interpretation of the many specification requirements. Obviously, the size of the commentary imposes restrictions on the extent of coverage on a given requirement.

This commentary is not intended to provide a historical background of the development of this specification, nor is it intended to provide a detailed resume of the studies and research data reviewed by the committee in formulating the provisions of this specification.

This specification does not treat the selection of materials or the sizing of the weld joints. Such considerations are assumed to be covered elsewhere; that is the statement of work, corporate design manuals, etc.

The committee has endeavored to produce a useful document suitable in language, form, and coverage for welding in the Aerospace and Aircraft industry. The specification provides a means for establishing welding standards for use in the design and construction by the customer or the Engineering Authority. The specification includes provisions for the regulation of welding that are necessary for public safety.

The committee recommends that the customer or the Engineering Authority be guided by this commentary in application of the specification to the welded structure. The commentary is not intended to supplement code requirements, but only to provide a useful document for interpretation and application of the specification; none of its provisions are binding.

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It is the intention of the Committee on Welding in the Aircraft and Aerospace Industries to revise the commentary on a regular basis so that commentary on changes to the specification can be promptly supplied to the user. In this manner, the commentary will always be current with the edition of the specification for fusion welding Aerospace structures with which it is bound.

## **E1. General Requirements**

**E1.1 Scope** This specification provides general welding requirements applicable to aerospace welded structures. It replaces MIL-STD-2219, *Fusion Welding for Aerospace Applications*, and MIL-STD-1595, *Qualification of Aircraft Missile and Aerospace Fusion Welders*, and is intended to complement any specification for the design and construction of aerospace and aircraft structures. When using this specification, customers and the Engineering Authority should recognize that not all provisions may be applicable or suitable to their particular structure.

Because of the diversity of the mission and systems criteria for aerospace structures, the specification committee allows modification of the provisions when deemed necessary by the Engineering Authority and when supported by engineering data. All modification of specification provisions should be clearly referenced in the contractual agreement between the customer and the Engineering Authority.

**E1.1.1. Flight Hardware.** In the United States, nonmilitary flight structures, including engines, used for commercial and general aviation are subject to the requirements set forth in the Code of Federal Regulations (CFR), Title 14. The parts of the CFR most directly applicable to D17.1/D17.1M are Parts 23, 25, 27, 29, 33, and 43.

**E1.1.2 Nonflight Hardware.** Contract requirements in the aerospace industry may not distinguish between welding intended for flight hardware (engines, structures, and flight systems) and welding for support functions (nonflight systems, tooling, ground support equipment, and related nonconventional facilities). For this reason, it was necessary to create Clause 9.

**E1.1.3 Crewed Spaceflight Hardware.** Spaceflight hardware that is intended for crewed missions is governed by NASA-STD-5006. Clause 10 is intended to supplement AWS D17.1/D17.1M to meet NASA-STD-5006 requirements.

**E1.2 Units of Measure.** For historical purposes, the units of measure have been standardized on the U.S. Customary Units, with close equivalents in International System Units. The engineering documentation units should drive which measurement units are used during welding and inspection.

**E1.3 Safety.** This specification cannot address all the safety and health regulations that apply to welding in every region where welding may occur. Therefore, some reference information is provided for the users to review for a better understanding of the risks of using these processes. But users need to review and comply with the health and safety regulations that apply to the region they are in. Some companies will institute more stringent requirements above local health and safety regulations.

**E1.4 Classification.** Aircraft and aerospace structures are classified according to structural integrity requirements, and welds in these structures commonly are subject to the same classifications. However, when design analysis can demonstrate that the weld(s), or a portion of the weld(s) in the structure is/are not subject to the same structural integrity requirements or loads as the rest of the structure, these welds may carry different classifications.

*MIL-STD-2219 provided the following nonmandatory clarification for the use of weld classifications A, B, and C:*

*Class A: Critical applications. Welds the single failure of which would cause loss of system, loss of major component, loss of control, unintentional release of critical stores, or inability to release armament stores, or endangering personnel.*

*Class B: Semicritical application. Welds where a failure would reduce overall efficiency of the system, preclude the intended function or use of the equipment; but loss of the system or endangering of personnel would not be experienced.*

*Class C: Noncritical application. Welds where a failure would not affect the efficiency of the system or endanger personnel.*

In general, much of the weld design data for Class A and Class B welds used in the aircraft and aerospace industry was derived from statistical analysis of data derived from test welds, and studies of weld defects. The extent of the testing may not be consistent from base metal/filler metal combination to base metal/base metal combination or gauge to gauge. Early industry databases generated in the 1950s and 1960s established acceptance standards that were related to workmanship standards and did not reflect the fracture toughness characteristics of the various material/filler metal combinations.



Consequently, there may be a degree of conservatism in the application of acceptance standards to welds in certain materials, while in others the standards may be too liberal. When selecting the appropriate weld classification and the extent of inspection, the Engineering Authority should consider not only the structural integrity requirements, but the ability to inspect, repair, or replace during the design life of the structures.

This specification recognizes that there are other factors that may enter into the selection of weld classifications and consequently uses weld classifications to identify the level for inspection and the acceptance criteria. The reason for this approach is that two identical welds may be exposed to different environments, have different degrees of accessibility for maintenance inspection during its design life, and be subject to different loading conditions (i.e., static versus dynamic). It is incumbent on the Engineering Authority to establish the weld classification that is both cost effective and ensures the structural integrity of the weldment for any given application.

**E1.7 Design Definitions and Requirements.** This clause recognizes that design definition may be one of many formats and that the generic reference to engineering drawing, etc. also refers to those other formats.

**E1.8 Exclusions.** In the past, there were instances where design documents specified AWS D17.1 for in-process welding of castings, however, this specification has never adequately covered such welding. This edition clarifies that in-process welding of castings at the fabricating foundry is outside the scope of this specification. This exclusion covers the in-process welding, the qualification of the personnel performing those in-process welds, and the qualification of the procedures for those in-process welds. SAE AMS established and maintains AMS2694 expressly for that purpose.

## **E2. Normative References**

Government standards organizations and industry standards organizations maintain their standards to be in line with current practices, technology, and regulatory requirements. Expect that there will be periodic changes to reference standards. It is important to clearly understand the effective edition of any given reference standard. In the case of undated references, the contract or purchase order can explicitly define the effective date, which then controls the edition. When explicitly defined, it is typically the edition of the reference in effect at the date of the contract or purchase order rather than the latest edition in effect at the time of fabrication.

In some situations, the latest edition of a standard in effect may be a cancellation notice or a supersession notice. The text within a supersession notice provides clear direction on the replacement standard to use. Carefully review the text within a cancellation notice to determine whether there is mandatory direction on the required replacement provisions. In the absence of mandatory direction, consult with the Engineering Authority to determine suitable replacement provisions.

## **E3. Terms and Definitions**

The purpose of the Terms and Definitions clause is to define terms that are unique to the aircraft and aerospace industry or may have a meaning different than in other fabrication industries.

## **E4. Design of Welded Connections**

**E4.1 Scope.** The ability of a weld to achieve its purpose or mission starts with the design process. Neither fabrication prowess nor inspection detection capability can overcome a poor or inadequate design. The design process, in a large part, will set the baseline for fabrication and life costs of the weldment. Weld joint selection and joint location play a major role in a weld's manufacturability and inspectability. Joint accessibility for both welding and inspection provides a good basis for a sound weld. It is important that the design process considers fabrication and inspection techniques necessary to produce an acceptable weld.

**E4.2 Weldment Design Data.** The first step in the design process should be to ensure that there is adequate data that reflect the performance of the weld zone under the anticipated loading conditions. This weld zone includes the weld metal and the adjacent parent metal, or heat-affected zone (HAZ). All of the components of the weld zone, not just the weld metal, make up the weld joint.

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The weld joint performance and properties are often affected by subsequent processing. This processing includes heat treatment, forming, or peening, to name a few. Consideration of weld discontinuities is a part of sound design analysis. It is important to remember that fusion welding is an in-situ casting process and weld metal discontinuities often occur.

The presence or absence of weld reinforcement, or the use of weld lands, determines which area of the weld zone drives performance: the weld, the HAZ, or parent metal. Weld lands are sometimes used where the joint strength, or other properties, are less than the parent metal.

Shrinkage and the resulting residual stress are normal occurrences in fusion welding. The residual stress present will affect the performance of the weld zone. Under some loading conditions this effect will be deleterious. Steps may be necessary to either reduce the residual stress in the weld zone with a postweld treatment or to compensate for its effects by modifying the weld joint design. In the case of shrinkage, preweld joint details may include added material to allow the weldment to meet postweld dimensional requirements.

### **E4.3 General Drawing Requirements**

**E4.3.1 Drawing Information.** There should be sufficient unambiguous information concerning the size, extent, type, location, and inspection requirements for the welds on the engineering drawing to allow the fabricator to produce the welds. The engineering drawing is often the sole mechanism by which the Engineering Authority communicates the weldment requirements to the fabricator and the inspector. There are some cases where the standard symbols of AWS A2.4 do not adequately describe the required weld and inspections. In these cases, the Engineering Authority should add enough additional information, often in the form of weld details, to the engineering drawing to provide reasonable assurance that the fabricator understands what type of weld to produce and how to inspect it.

**E4.3.2 Groove Welds.** Full penetration groove welds are the default requirement. Full penetration welds do not have the built-in weld root discontinuity that is always present in a partial penetration weld joint. Thus, the internal examination of full penetration groove welds for discontinuities is more straightforward than that for partial penetration groove welds. The effective area of a groove weld coupled with the weld metal strength indicates the load-carrying capacity of the weld metal. Weld reinforcement is not considered when calculating the effective area of a groove weld for loading analysis because reinforcement is of little benefit to the load-carrying capacity of the weld joint.

**E4.3.3 Fillet Welds.** The typical practice in welding is to specify the fillet weld size as a minimum with the maximum size controlled by the governing fabrication specification. However, stating a specific maximum weld size is prudent when mechanical interference may occur at a higher assembly level. The effective area of a fillet weld coupled with the strength of the weld filler metal in shear determines the strength of the fillet joint. Some fillet weld metals may have shear strength values that differ according to the direction of the applied shear stress. The principal shear stress directions are parallel or perpendicular (longitudinal or transverse) to the length of the fillet weld.

In this specification the minimum distance from the design joint root to the face of the triangle representative of the fillet weld cross section for the minimum allowable size is the effective throat. The definition here is consistent with that in AWS D1.1/D1.1M but differs from AWS A3.0M/A3.0. Because fillet welds are triangular in cross section (often a right triangle), increasing the effective throat requires a disproportionate amount of additional weld metal. For example, changing the fillet weld size from 1/8 to 3/16 in [3.2 to 4.8 mm] in a 90-degree equal leg fillet weld with no root gap increases the effective throat by a factor of 1.5 while weld metal volume increases by a factor of 2.25. This modest joint strength boost comes with a proportionally larger potential for distortion.

**E4.3.4 Essential Information.** The eight listed categories provide the minimum drawing information sufficient to address most situations. It is incumbent upon the Engineering Authority to add additional requirements to the engineering documentation when warranted. The Engineering Authority has met its obligations when all essential information required to successfully perform the weld has been unambiguously documented.

**E4.3.5 Inspection Requirements.** It is important to establish both the appropriate inspections and acceptance criteria for each weld joint or separate regions within the weld joint, based upon the service loading conditions. The weld joint classifications A, B, and C provide suitable levels of inspection and acceptance criteria. The Engineering Authority may tailor inspection and acceptance criteria for each weld to best suit the application and the loading conditions.

Inspections and acceptance criteria applied generically to a weldment may lead to under-inspection of some welds and over-inspection of others. Consider the practicality of meeting the acceptance criteria chosen. Choosing acceptance criteria beyond the capability of the welding process may lead to numerous inspection rejections, increasing costs. Every



inspection technique has its own weld joint access requirements and detection limitations. Designs and/or the inspection process(es) selected may require reevaluation if the acceptance criteria are beyond the detection capability of the inspection process(es).

## **E5. Welding Procedure and Performance Qualification**

The fundamental purpose of the welding procedure and performance qualification clause of this specification is to provide basic requirements applicable to most situations. The purpose of welding procedure qualification is to verify the soundness of the welded joint produced by a documented welding procedure. The purpose of performance qualification is to verify the ability of a welder, welding operator, or tack welder to produce an acceptable weld in accordance with a documented welding procedure. When necessary, this specification allows latitude for the use of Engineering Authority's judgment.

This edition continues with the practice of specifying default requirements for procedure qualification, which the Engineering Authority can use as is, make additions, or make exceptions to as necessary.

**E5.1 General.** As a reminder, MIL-STD-1595A and MIL-STD-2219 were used as the basis for this clause. It continues to evolve with each revision.

With many acquisitions, mergers, divestitures, and name changes occurring in the industry, many companies were facing challenges with the terminology of older revisions. Clarification was added to allow fabricators to continue using legacy qualification and procedure documents regardless of name or ownership changes.

Bend testing is specified for both procedure and performance qualifications. Rather than specifying both AWS B4.0 and Annex B, the necessary details from AWS B4.0 have been added to Annex B.

**E5.2 Welding Procedure Data and Qualification.** All welding requires working to a written Welding Procedure Specification (WPS). The required content of the WPS has been specified in Table 5.1. As stated in 5.2.2, "WPSs for Class A and B welds shall have a supporting PQR." The purpose of weld qualification is to demonstrate, with test data, that the weld process and materials are compatible, yield acceptable results, and meet the requirements of this specification. WPSs for Class C noncritical welds, do not require qualification data. Suggested format for WPSs and PQRs is in Annex F.

The manual or semi-automatic welder with a protective hood down is unable to view amperage or voltage meter readings, or to accurately estimate travel speed. Consequently, Table 5.1 does not require specifying these variables for manual or semi-automatic welding applications. Aerospace and Aircraft welder qualification/certification requirements often exceed structural welding qualification requirements. Other methods have been defined and used to capture and maintain the necessary control. One method, when welding with GTAW, is to specify a single tungsten electrode size, electrode tip preparation geometry, and shielding gas setting. This results in a more practical and measurable method for controlling the amperage rather than having to specify a specific amperage level. A certified welder is trained to recognize weld puddle behavior.

It is possible to achieve more predictable welding outcomes through the use of a structured approach using defined and validated variables specified in a written weld procedure. The welding procedure could include variables such as: type of gas, AC or DC current, polarity, tungsten geometry, base metal alloy (and condition), filler type and diameter, torch size, cup size, lead/lag angle, appropriate fixturing, joint backup gas or other, shielding trailers, gas flow and most important "specifics" for successful welding of the given component. The basic rule is if the welder can control a welding variable during the welding process (hood up), such as those listed above, they are to be specified/qualified on the weld procedure specification/weld schedule and locked down to specific parameters. Welding variables that cannot be controlled by the welder when welding (hood down) need not be listed on the weld procedure.

**E5.3 and E5.4 General and Detailed Performance Qualification.** Formatting and wording was changed to clarify the intent of these sections.

**E5.3.2 Vision Requirements.** In previous editions, there were requirements for eye exams which required select tests. With more global or international companies utilizing the specification, provisions were added to allow for the use of alternative tests which are widely accepted among professionals as being equivalent or are testing for the same abilities.

Some companies also have internal staff that administer other medical tests, exams, etc. Although not formally trained as optometrists, if they have undergone sufficient training, they may be appointed to administer the tests required by this specification.

**E5.3.4 Extended Validity.** A welder qualification can be extended indefinitely provided they begin tracking activity from the original certification date, there is no period 6 months or longer of inactivity or lack of documentation, and there is no other reason to question the welder's ability. The qualified applications based on a given test are no longer listed in a clause format. Instead, a table format was used to improve the useability of the document.

**E.Figures 5.11-5.14.** Figures showing weld cross sections, profiles, melt-through, and cases of acceptable incomplete fusion to the root in fillet welds have replaced the previous figures.

## **E6. Fabrication**

**E6.1 Scope.** The fundamental purpose of the Fabrication clause of this specification is to provide basic requirements applicable to most situations. When necessary, it allows latitude for use of the engineering judgment by the Engineering Authority.

**E6.2 Welding Consumables.** Due to the criticality of many aerospace weldments, the identification, storage, and the use of all welding consumables (including wires, rods, inserts, fluxes, gases, etc.) require proper controls. Many failures have been attributed to using the incorrect material during welding. The intent of this section is to provide the minimum controls necessary to control all consumables.

**E6.3 Welding Equipment.** A certain minimum amount of maintenance, possibly including periodic calibrations, is necessary to prevent equipment-related weld defects. Calibration should also be performed when there is reason to question the capability of the machine to produce acceptable welds.

**E6.4 Machine Welding Parameters.** The committee has written the specification with the intent that weld settings from the qualified WPS are used during the production welding to maintain maximum repeatability. For manual welding, the qualified WPS will generally not list those parameters that are not fixed prior to the start of welding. These parameters vary with process but may include arc voltage, current, and travel speed.

After a major repair of mechanized or automatic welding equipment, it is important to prepare and test the reproducibility test weld to ensure proper operation of the equipment. Reproducibility test weld should also be used to determine and remedy continual quality problems in the weld shop.

**E6.5 Preweld Cleaning and Other Preparation.** Before welding the joint surfaces should be properly cleaned, (chemically and/or mechanically) and then protected from contamination. This preparation procedure should be documented and consistently followed. Select cleaning solvents have been identified as causing/contributing to welding related discontinuities, defects, or failures within given material classes and are therefore prohibited.

**E6.6 Preweld Joint Preparation and Fitup.** Proper joint preparations and adhering to fitup gap requirements will reduce or eliminate problems associated with weld penetration, distortion, and mismatch.

**E6.7 Preheating and Interpass Temperature Control.** Although Table 6.2 provides recommended preheat and interpass temperatures for certain materials, it is the fabricator's responsibility to establish these temperatures. The fabricator, at minimum, should consider the material's chemical composition, metallurgical properties, and the part's integrity requirement during the establishment of the preheat and the interpass temperature controls. Preheat and interpass temperature listed on the qualified WPS must be used and maintained during production welding.

**E6.8 Tack Welds.** Qualification variables, including filler material, should be specified in the WPS. Experience has proved the need to either fully consume the tack weld in the next weld pass or remove the tack welds before next weld pass. It is important to be aware of fitup requirements prior to tacking as well as preheat requirements as documented on the WPS.

**E6.9 Weld Start and Run-Off Tabs.** Many common start/stop defects can be eliminated from the welded joint by the use of tabs. It is important that tabs be of the same material as the base metal because of the mixing of the metals in the weld pool.



**E6.10 Weld Shielding for GTAW, GMAW, and PAW.** The weld and heat-affected zone should be shielded during the welding process to prevent defects caused by oxidation. Reactive base metals, such as titanium and its alloys, require special attention in shielding. In such materials, deposited and solidified weld metal immediately behind and a certain distance beyond the progressing weld pool must also be shielded to preclude contamination. AWS G2.4 provides guidelines for the shielding of titanium and its alloys. The consumables, such as shielding gases, fluxes, etc., should always be listed in the WPS.

**E6.11 Tungsten Electrodes.** AWS A5.12M/A5.12, *Specification for Tungsten and Oxide Dispersed Tungsten Electrodes for Arc Welding and Cutting*, is the industry standard for tungsten electrodes used in GTAW and PAW.

**E6.12 Filler Materials.** Filler materials change the metallurgy of the weld. In some cases, it can be used to increase the weldability of a material or provide additional strength. Therefore, it is always incumbent on the Engineering Authority to choose the filler material for the property sought. For guidance, Annex 1.2(a), 1.2(b), and 1.2(c) provide filler materials typically used in welding aerospace base materials.

**E6.13 Interpass Cleaning.** Interpass cleaning in a multipass weld is important in obtaining a weld with acceptable quality. This step will remove contaminants, such as oxides and slag, deposited on the weld bead or joint surface during previous weld pass(es). Chemical or liquid solutions are not recommended because of the difficulty of their removal. Cleaning of titanium weldments is not performed until after inspection to verify that the weld does not contain oxygen contamination represented by specific types and forms of discoloration.

**E6.17 Weld Identification Requirements.** The intent is that weldments will have traceability to their welder. A structurally critical weld, defined as such by the Engineering Authority, will typically have traceability and processing history that is documented and maintained through the life of the product. Typically, the fabricator is responsible for maintaining all traceability and processing documentation for a period defined by the Engineering Authority or a contract document.

**E6.19 Rework.** Historically, any rework should be completed using the same welding process(es) as was used to make the original weld. Because some applications may not lend themselves to using the original process(es), the use of the GTAW process can be implemented if the NDE and mechanical requirements of the original design are met. With the heat sensitivity of some materials, the rework documentation should readily illustrate the rework process and number of attempts that can be performed.

**E6.20 Repair.** This activity takes place on the rejected part dispositioned by the Engineering Authority for a repair. Usually, the Engineering Authority disposes a rejected part for a repair when it is deemed possible to correct and bring the weld or the part within the specified acceptance, integrity, and/or functional requirement. All operations involved in this activity are a part of the disposition from the Engineering Authority. The fabricator and the welder must follow provided directions.

Some examples of the disposition to repair a rejected part include, but are not limited to:

- (1) welding from the root side to correct incomplete penetration,
- (2) welding on a heat-treated part,
- (3) additional weld on the part to bring the part within the dimensional or the configuration requirement of the drawing,
- (4) welding to correct an unintentional gouge or a nick,
- (5) weld was made using filler metal other than that specified by the Engineering Authority.

## E7. Inspection

**E7.1 Qualification of NDE Personnel.** Clause 7.1.2 now provides clear requirements for the qualification of visual weld inspectors. Certification of visual weld inspectors can now be per one of three methods: AWS QC1; by a certification program approved by the Engineering Authority; or by a certification program approved by the fabricator's quality organization management. If the fabricator's quality organization management approval program is used, it must be based on experience, training, and testing criteria cited in AWS B5.2.

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Clause 7.1.3 contains requirements for near vision and color perception tests administered to the visual weld inspector. The criteria detailed here has been largely standardized to align with the welder/welding operator visual testing requirements. These tests could now be any that is selected by the test administrator. It has removed the use of Jaeger J1 at 12 in [300 mm] and Jaeger J2 at 16 in [405 mm], a requirement that was in the previous edition. It now allows use of Snellen and tumbling E chart, or any other world language letter, or any character or symbol as deemed appropriate by the personnel administering the test. This change now recognizes various areas of the world where English may not be the primary language of the communication.

**E7.2 Visual Weld Inspection.** Clause 7.2 in this revision has the requirement to inspect all welds visually the same as was in the previous edition. All welds should be visually inspected prior to subjecting them to other NDE examinations. Visual inspection should be for any surface defect easily discernible and acceptable or rejectable using measurement tools (gauges and scales) as specified in Table 7.1 by the visual weld inspector (e.g. lack of penetration, crack, weld reinforcement, fillet weld sizes, discoloration, and any other within Table 7.1). This clause, however, does not explicitly require the visual inspection of inaccessible root surfaces. It is important for Engineering to recognize when the root side of the weld may not be accessible for visual inspection, and, if necessary, specify supplemental inspections such as borescopy or radiography to verify the root side quality.

**E7.3.1 Penetrant Testing (PT).** All Class A and B welds in nonferromagnetic materials (e.g., aluminum, titanium, austenitic steels, copper) are required by this specification to be penetrant tested. This inspection method only detects flaws open to the surface and not to the subsurface. All defects detected by penetrant technique are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Class A or B welds in ferromagnetic materials (e.g., carbon and alloy steels, martensitic and duplex stainless steels, and most PH stainless steels) are not required to be subjected to penetrant testing unless so required on the engineering drawing or by the Engineering Authority. When the engineering requires inspection of ferromagnetic materials using penetrant testing, all defects detected by penetrant technique are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Similar to visual weld inspection, penetrant testing of inaccessible weld root side surface is not explicitly required unless the requirement is specified by the Engineering Authority. In lieu of inspecting such inaccessible surfaces by penetrant testing method, use any other method deemed appropriate by the Engineering Authority. It is important to get this waiver or approval when particular root surface is considered inaccessible by the fabricator prior to inspection initiation.

If for any reason, weld surfaces are ground, penetrant specifications require those surfaces to be prepenetrant etched prior to subjecting the surface to penetrant testing methods. However, it is important to keep in mind that etching solutions, when trapped and remained or dried up (especially on root side of weld) without complete removal, can result in initiation and propagation of corrosion pits and stress corrosion cracking. It is important for the fabricator to reach an agreement with the Engineering Authority when to omit such prepenetrant etching operations for a particular weldment.

Type I penetrant removable by any method and sensitivity level 2 or better is required to be used in penetrant testing. It is important to understand requirements in NDE inspection documents specified on engineering or other aerospace documents such as Department of Defense documents (e.g., NDE Manual TO 33-B1.1). Engineering specified or other documents may prohibit use of particular types of penetrant materials (e.g., water washable penetrants).

**E7.3.2 Magnetic Particle Testing (MT).** All Class A and B welds in ferromagnetic materials (e.g., carbon and alloy steels, martensitic and duplex stainless steels, and most PH stainless steels) are required by this specification to be magnetic particle tested.

This inspection method is primarily used to detect defects open to surface.

Discontinuities detected by particle testing are required to be evaluated and accepted or rejected on the basis of requirement in Table 7.1.

Similar to visual weld inspection, penetrant examination of inaccessible weld root side surface is not explicitly required unless the requirement is specified by the Engineering Authority.

**E7.3.3 Radiographic Testing (RT).** All Class A groove welds are required by this specification to be radiographically tested. This inspection method detects volumetric defects. The limitation of this method of examination is the size of the defect in relation to the thickness of the material being inspected. All defects detected by radiographic testing are to be



evaluated and accepted or rejected on the basis of requirement for subsurface flaws in Table 7.1, which is the reason that surface examination techniques are performed by methods other than radiographic examination.

Ensure that a written procedure that includes a technique data sheet is developed based on the part geometry as specified in ASTM E1742 and used during inspection of the part.

Class B and Class C welds are not required to be radiographically tested unless specifically required by engineering. When engineering does not require radiographic testing of Class B and Class C welds, neither subsurface (volume between face and root surface) flaw/defect criteria specified in Table 7.1 apply.

With the advances of computed radiography and digital radiography, the nondestructive testing industry has recognized these techniques as being equivalent to film radiography. The committee has recognized this technological advance in this specification and allowed the use of the nonfilm inspection techniques referenced in ASTM E1742. Using this approach, if future technology changes are specified in ASTM E1742, they can be easily incorporated into the aerospace welding industry.

**E7.3.4 Ultrasonic Testing (UT).** Ultrasonic testing may be used as an alternative to radiographic testing. It is performed only when specified on drawing, contract, or by the Engineering Authority. The default specification for ultrasonic testing is ASTM E164.

Since the ultrasonic examination technique is in lieu of or alternative to radiographic examination, it should be used to detect defects lying below the surface. All subsurface defects detected by ultrasonic technique are required to be evaluated and accepted or rejected on the basis of requirement for subsurface flaws in Table 7.1.

Class B and Class C welds are not required to be ultrasonically tested, similar to radiographic testing, unless specifically required by engineering. When engineering does not require ultrasonic testing of Class B and Class C welds, neither subsurface (volume between face and root surface) flaw/defect criteria specified in Table 7.1 apply.

**E7.3.5 Proof Testing (PRT).** Proof testing is performed when specified on drawing or contract, or when required by Engineering Authority. In such cases, a proof test should not commence until all required specimen configurations, test methods and procedures, and acceptance criteria are received from the Engineering Authority.

**E7.4 Acceptance Criteria. Requirement of Table 7.1.** Table 7.1 provides inspectors one single location for acceptance criteria. Subsurface requirements in Table 7.1 are only applicable when radiographic (see requirement in 7.3.3) or ultrasonic examination (see requirement in 7.3.4) has been specified.

**Requirements of Figure 7.1.** Figure 7.1 has been revised to eliminate terms that are defined by AWS A3.0, resulting in making this figure only applicable to fillet welds. The allowance of the presence of melt through has been added to Figure 7.1, making this condition acceptable on production parts, within the limits specified. The requirements are based on those allowed for personnel and procedure qualification per Figures 5.13 and 5.14.

**Figure 7.2.** Illustrates various cases of mismatch that may be encountered. When components of differing thicknesses are encountered, it is only considered mismatch if the thinner member extends outside of the boundaries of the thicker material.

## **E8. Repair of Existing Structures**

**E8.1 Scope.** The purpose behind the clause on repair welding is to establish a consistent systems approach for in-service weld repairs to aviation flight hardware. This will include all primary and secondary structures and component repairs. This system's approach will follow the general format of the main and subclauses of D17.1/D17.1M for application of a welding repair. In general, there are weld repairs to in-service components performed every day at repair stations or other FAA-approved facilities and this clause of the welding specification may or may not apply to those repairs. The decision to apply this clause resides with the Engineering Authority and the governmental regulating agency, as permitted by the Code of Federal Regulations (Title 14, Parts 43 and 145). The final authority for all approvals for weld repair procedures resides solely with the governmental regulating agency.

*NOTE: When the weld repair becomes an integral part of flight hardware maintenance, Clause 8 will apply.*

Generally, an overhaul manual approved by the governmental regulating agency will contain established weld repair procedures that are acknowledged and approved by the FAA for use by Repair Stations or the OEMs as permitted, without

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additional qualification or requalification of which are used for generic or common weld repairs. That distinction is limited for weld repairs to flight hardware on structures which have limited or unsatisfactory weldability, such as aluminum alloy 7075-T73. As corrosion and fatigue begin to affect the base metal in critical areas, the Engineering Authority will need to investigate and develop economical means to repair welding. This will prompt the welding industry to develop new uses for current and future technologies.

**E8.2 Design.** Stress analyses performed to satisfy design requirements could vary from performing qualitative engineering assessment of loading to a detailed finite element analysis of the repaired area.

**E8.3 Welding Procedures.** Originally, most weld procedures may not have been qualified or have had an adequately documented weld procedure. Where welds become an integral method of fabrication, the need and requirement for developing and documenting the weld procedure becomes an important aspect of weld repairs.

This clause of the specification prohibits the weld repair application unless sufficient testing has been performed. The testing of the weld repair procedure must satisfactorily apply to the specific application. This will include weld repair procedures that may have been previously qualified for another application or base metal/weld metal combination. If sufficient data exists to support another similar application, the Engineering Authority may approve the weld repair procedure for additional uses.

The actual application of the weld repair procedure must be the controlling factor when following previously qualified weld procedures.

**E8.4 Welder and Welding Operator Qualification.** For qualification of personnel to perform repair welding on existing hardware, the same requirements are applied that would be used to build new hardware. The same ability is necessary to obtain acceptable welds.

**E8.6 Weld Repair Inspection.** In most cases, the currently specified inspection methods are adequate for weld repairs. When the inspection is not normally used for the item because of limitations of the method, the Engineering Authority may authorize alternative inspection methods if the current method is not sufficient. Approval from the appropriate government agency is required. Each weld repair in areas not normally inspected should have adequate Engineering oversight, ensuring the adequacy of the repair inspection.

**E8.7 Grounding and Bonding.** Welding on aircraft poses additional risks to other hardware. With the complex electronics and moving parts on the vehicle, the Engineering Authority needs to verify that there will not be damage to these other components from the electrical path to workpiece lead.

**E8.8 Repair Documentation.** The use of welding to repair items that are not normally welded is a very possible situation and the need to document the location of the weld repair is critical to track and monitor the repair in the event of failure. Weld repairs performed per this clause have inherent liability issues and documentation of the repair is important to provide a long-term record of the suggested welding variables listed in this clause. The variables listed in Clause 8 are not all inclusive and may be changed by adding or deleting some of the welding variables depending on the welding procedure development. The documentation provides feedback to the extent the weld repair was utilized and any corresponding corrective action taken is properly documented.

## **E9. Nonflight Hardware**

This specification recognizes fundamental differences between welding flight and nonflight structures (which are often overlooked in contracts), and allows for their unique requirements to be covered by a single master specification.

**E9.1 Scope.** The typical aerospace hardware considered herein support the operations of manufacturing, transporting, receiving, handling, assembly, inspection, test, checkout, and service of aircraft, missile and space vehicles and payloads, and the launching of small or ballistic missiles, space vehicles, and payloads.

**E9.2 Exceptions and Additional Requirements.** This clause is intended to establish uniform practices for the design, qualification, fabrication, and inspection of nonflight hardware. This goal is accomplished by combining the requirements of consensus industrial welding codes with supplementary requirements as necessary. Supplementary requirements were added in areas where the pertinent industrial code either contained no requirements or contained requirements insufficient for aerospace applications. This approach is consistent with the intended use of the referenced codes which typically establish minimum requirements. For example, even though AWS D1.1/D1.1M, *Structural Welding Code — Steel*,



contains requirements for NDE methods and acceptance criteria, NDE is not required unless specifically requested in the contract agreement (such a request would be separate from the general AWS D1.1/D1.1M callout and would have to contain details on the desired methods and extent of examination). A normative annex in AWS D1.1/D1.1M contains examples of how to write a specification that invokes some of the optional provisions of that code. ASME B31.3, *Code for Pressure Piping—Process Piping*, states that “The owner is also responsible for imposing requirements supplementary to those of the code if necessary to assure safe piping for the proposed installation.” Some additional examples of the supplementary requirements are the following:

- (1) data requirements for engineering drawings
- (2) requirements for material certifications
- (3) requirements for structural welding of nontraditional structural alloys
- (4) provisions for verification of WPS and welder qualifications
- (5) fabrication techniques, including preheating and postweld heating requirements
- (6) requirements for visual inspection and NDE (including personnel qualification, methods, extent, and acceptance criteria) as well as rework.

Excluded from the requirements of Clause 9 are pressure vessels for nonflight applications which should be fabricated in accordance with the ASME *Boiler and Pressure Vessel Code* (BPVC). Supplementary requirements are not added to the ASME BPVC due to the fact that the BPVC directly links weld design factors (e.g., joint efficiencies and allowable stresses) to the type and extent of NDE performed, and also establishes extensive requirements for such subjects as weld categories, weld types, service restrictions, and fabrication details (including detailed requirements for postweld heat treatment). Furthermore, the ASME BPVC states that engineering judgment used in the application of the BPVC “must never be used to overrule mandatory requirements or specific provisions of the Code.”

## **E10. Crewed Spaceflight Hardware**

The purpose of the Crewed Spaceflight Hardware clause is to give the customer the option to use AWS D17.1 for spaceflight hardware that is intended for crewed missions where NASA-STD-5006 is the requirement. The supplemental requirements contained within this clause, together with all previous flight hardware requirement clauses of this specification, meet the intent of NASA-STD-5006. The Crewed Spaceflight Hardware clause is to be invoked via the engineering drawing requirements and should be specified in the procurement specification.

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## **Annex F (Informative)**

### **Samples of Welding Forms for WPSs, PQRs, and Welder Performance Qualifications**

This annex is not part of this standard but is included for informational purposes only.

Excerpted from AWS D17.1/D17.1M:2024  
Under the authority of the American Welding Society  
All information is provided for informational purposes only

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**SAMPLE WELDING PROCEDURE SPECIFICATION (WPS)  
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)**

|                     |  |  |  |               |  |                         |  |                                            |  |
|---------------------|--|--|--|---------------|--|-------------------------|--|--------------------------------------------|--|
| Company Name _____  |  |  |  | WPS No. _____ |  | Rev. No. _____          |  | Date _____                                 |  |
| Authorized by _____ |  |  |  | Date _____    |  | Supporting PQR(s) _____ |  | Fracture Toughness Test (FTT) Report _____ |  |

| BASE METALS      |               |   |       |                           | Thickness Range |        |
|------------------|---------------|---|-------|---------------------------|-----------------|--------|
| Specification    | Type or Grade | M | Group |                           | As-Welded       | w/PWHT |
| Base Material    |               |   |       | Groove Welds              |                 |        |
| Welded To        |               |   |       | Groove w/FTT              |                 |        |
| Backing Material |               |   |       | Partial Pen. Groove Welds |                 |        |
| Other            |               |   |       | Fillet Welds              |                 |        |
|                  |               |   |       | Pipe/Tube Diameter Range  |                 |        |

| FILLER METALS |       |                |       |       |            | Thickness Range                                                                                   |        |
|---------------|-------|----------------|-------|-------|------------|---------------------------------------------------------------------------------------------------|--------|
| Process       | Spec. | Classification | F-no. | A-no. | Trade Name | As-Welded                                                                                         | w/PWHT |
| Process 1     |       |                |       |       |            |                                                                                                   |        |
| Process 2     |       |                |       |       |            |                                                                                                   |        |
| Process 3     |       |                |       |       |            |                                                                                                   |        |
| Cons. Insert  |       |                |       |       |            | <input type="checkbox"/> Required <input type="checkbox"/> Optional <input type="checkbox"/> None |        |
| Flux          |       |                |       |       |            | <input type="checkbox"/> Required <input type="checkbox"/> Optional <input type="checkbox"/> None |        |
| Sup. Filler   |       |                |       |       |            | <input type="checkbox"/> Required <input type="checkbox"/> Optional <input type="checkbox"/> None |        |

| JOINT DETAILS |  |
|---------------|--|
| Groove Type   |  |
| Groove Angle  |  |
| Root Opening  |  |
| Root Face     |  |
| Backgouging   |  |
| Method        |  |

**JOINT DETAILS (Sketch)**

Sketches, production drawings, welding symbols, or written description should show the general arrangement of the parts to be welded. Where applicable, the root details of the weld groove may be specified.

| POSTWELD HEAT TREATMENT |  |
|-------------------------|--|
| Temperature             |  |
| Time at Temperature     |  |
| Other                   |  |

| PROCEDURE                           |  |  |  |  |
|-------------------------------------|--|--|--|--|
| Weld Layer(s) / Pass(es)            |  |  |  |  |
| <b>Process</b>                      |  |  |  |  |
| Type (Manual, Mechanized, etc.)     |  |  |  |  |
| <b>Preheat Temperature</b>          |  |  |  |  |
| Interpass Temperature               |  |  |  |  |
| <b>Filler Metal Size</b>            |  |  |  |  |
| <b>Position</b>                     |  |  |  |  |
| Vertical Progression                |  |  |  |  |
| <b>Shielding Gas Compos. (GTAW)</b> |  |  |  |  |
| Flow Rate (GTAW)                    |  |  |  |  |
| Nozzle Size (GTAW)                  |  |  |  |  |
| <b>Electrical Characteristics</b>   |  |  |  |  |
| Electrode Diameter (GTAW)           |  |  |  |  |
| Current Type & Polarity             |  |  |  |  |
| Amps                                |  |  |  |  |
| Volts                               |  |  |  |  |
| Cold or Hot Wire Feed (GTAW)        |  |  |  |  |
| Travel Speed                        |  |  |  |  |
| Maximum Heat Input                  |  |  |  |  |
| <b>Technique</b>                    |  |  |  |  |
| Stringer or Weave                   |  |  |  |  |
| Multi or Single Pass (per side)     |  |  |  |  |
| Oscillation (GTAW Mech./Auto.)      |  |  |  |  |
| Traverse Length                     |  |  |  |  |
| Traverse Speed                      |  |  |  |  |
| Dwell Time                          |  |  |  |  |
| Peening                             |  |  |  |  |
| Interpass Cleaning                  |  |  |  |  |
| <b>Other</b>                        |  |  |  |  |

**Figure E.1—Example of a Welding Procedure Specification**

**SAMPLE PROCEDURE QUALIFICATION RECORD (PQR)  
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)**

|              |         |          |      |
|--------------|---------|----------|------|
| Company Name | PQR No. | Rev. No. | Date |
|--------------|---------|----------|------|

| BASE METALS      | Product Form | Specification (Type or Grade) | M-No. | Group-No. | Thick. | Size | Sch. | Dia. |
|------------------|--------------|-------------------------------|-------|-----------|--------|------|------|------|
| Product Form     |              |                               |       |           |        |      |      |      |
| Welded To        |              |                               |       |           |        |      |      |      |
| Backing Material |              |                               |       |           |        |      |      |      |
| Other            |              |                               |       |           |        |      |      |      |

| JOINT DETAILS      |  |
|--------------------|--|
| Groove Type        |  |
| Groove Angle       |  |
| Root Opening       |  |
| Root Face          |  |
| <b>Backgouging</b> |  |
| Method             |  |

| JOINT DETAILS (Sketch)                                                                                                                                                                         |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Sketches, welding symbols, or written description should show the actual arrangement of the test coupon welded. Where applicable, the root details of the weld groove may be specified.</p> |

| POSTWELD HEAT TREATMENT |  |
|-------------------------|--|
| Temperature             |  |
| Time at Temperature     |  |
| Other                   |  |

| PROCEDURE                           |  |  |  |  |  |  |  |  |
|-------------------------------------|--|--|--|--|--|--|--|--|
| Weld Layer(s) / Pass(es)            |  |  |  |  |  |  |  |  |
| <b>Process</b>                      |  |  |  |  |  |  |  |  |
| Type (Manual, Mechanized, etc.)     |  |  |  |  |  |  |  |  |
| <b>Preheat Temperature</b>          |  |  |  |  |  |  |  |  |
| Interpass Temperature               |  |  |  |  |  |  |  |  |
| <b>Filler Metal (AWS Spec.)</b>     |  |  |  |  |  |  |  |  |
| AWS Classification                  |  |  |  |  |  |  |  |  |
| F-number / A-number                 |  |  |  |  |  |  |  |  |
| Nominal Composition                 |  |  |  |  |  |  |  |  |
| Manufacturer/Trade Name             |  |  |  |  |  |  |  |  |
| Size or Diameter                    |  |  |  |  |  |  |  |  |
| Deposited Thickness                 |  |  |  |  |  |  |  |  |
| Maximum Pass Thickness              |  |  |  |  |  |  |  |  |
| <b>Position</b>                     |  |  |  |  |  |  |  |  |
| Vertical Progression                |  |  |  |  |  |  |  |  |
| <b>Shielding Gas Compos. (GTAW)</b> |  |  |  |  |  |  |  |  |
| Flow Rate (GTAW)                    |  |  |  |  |  |  |  |  |
| <b>Trailing Gas Compos. (GTAW)</b>  |  |  |  |  |  |  |  |  |
| Flow Rate (GTAW)                    |  |  |  |  |  |  |  |  |
| <b>Backing Gas Compos. (GTAW)</b>   |  |  |  |  |  |  |  |  |
| Flow Rate (GTAW)                    |  |  |  |  |  |  |  |  |
| <b>Electrical Characteristics</b>   |  |  |  |  |  |  |  |  |
| Electrode Diameter (GTAW)           |  |  |  |  |  |  |  |  |
| Current Type & Polarity             |  |  |  |  |  |  |  |  |
| Amps                                |  |  |  |  |  |  |  |  |
| Volts                               |  |  |  |  |  |  |  |  |
| Cold or Hot Wire Feed (GTAW)        |  |  |  |  |  |  |  |  |
| Travel Speed                        |  |  |  |  |  |  |  |  |
| Maximum Heat Input                  |  |  |  |  |  |  |  |  |
| <b>Technique</b>                    |  |  |  |  |  |  |  |  |
| Cup or Nozzle Size (GTAW)           |  |  |  |  |  |  |  |  |
| Stringer or Weave                   |  |  |  |  |  |  |  |  |
| Multi or Single Pass (per side)     |  |  |  |  |  |  |  |  |
| Oscillation (GTAW Mech./Auto.)      |  |  |  |  |  |  |  |  |
| Traverse Length                     |  |  |  |  |  |  |  |  |
| Traverse Speed                      |  |  |  |  |  |  |  |  |
| Dwell Time                          |  |  |  |  |  |  |  |  |
| Peening                             |  |  |  |  |  |  |  |  |
| Interpass Cleaning                  |  |  |  |  |  |  |  |  |
| <b>Other</b>                        |  |  |  |  |  |  |  |  |

**Figure F.2—Example of a Procedure Qualification Record**

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**SAMPLE PQR (Test Results - Page 2)**  
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

|  |         |          |
|--|---------|----------|
|  | PQR No. | Rev. No. |
|--|---------|----------|

**TESTS**

| No. | Type of Tests | Clause / Figure(s)<br>Reference | Acceptance<br>Criteria | Result | Remarks |
|-----|---------------|---------------------------------|------------------------|--------|---------|
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |
|     |               |                                 |                        |        |         |

**TENSILE TEST DETAILS**

| Specimen<br>Number | Width | Thickness | Area | Ultimate<br>Tensile Load | Ultimate<br>Unit Stress | Type of Failure and<br>Location |
|--------------------|-------|-----------|------|--------------------------|-------------------------|---------------------------------|
|                    |       |           |      |                          |                         |                                 |
|                    |       |           |      |                          |                         |                                 |
|                    |       |           |      |                          |                         |                                 |
|                    |       |           |      |                          |                         |                                 |

**FRACTURE TOUGHNESS TEST DETAILS**

| Specimen<br>Number | Notch<br>Location | Notch<br>Type | Specimen<br>Size | Test<br>Temperature | Absorbed<br>Energy | Percent<br>Shear | Lateral<br>Expansion | Other |
|--------------------|-------------------|---------------|------------------|---------------------|--------------------|------------------|----------------------|-------|
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |
|                    |                   |               |                  |                     |                    |                  |                      |       |

**CERTIFICATION**

|  |  |  |  |
|--|--|--|--|
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared welded, and tested in accordance with the requirements of AWS D17.1/D17.1M ( ) Specification for Fusion Welding for Aerospace Applications.  
Year

|  |           |
|--|-----------|
|  | Signature |
|  |           |
|  |           |

**Figure E.2 (Continued)—Example of a Procedure Qualification Record**



SAMPLE PERFORMANCE QUALIFICATION TEST RECORD  
(SMAW, GMAW, GTAW, FCAW, OFW, PAW)

Ê

|           |  |                      |               |  |      |
|-----------|--|----------------------|---------------|--|------|
| Name      |  | OPTIONAL<br>PHOTO ID | Test Date     |  | Rev. |
| ID Number |  |                      | Record No.    |  |      |
| Stamp No. |  |                      | Std. Test No. |  |      |
| Company   |  |                      | WPS No.       |  |      |
| Division  |  |                      | Qualified To  |  |      |

| BASE METALS  | Product Form | Specification (Type or Grade) | Group Number | Size | Sch. | Thick. | Dia. |
|--------------|--------------|-------------------------------|--------------|------|------|--------|------|
| Product Form |              |                               |              |      |      |        |      |
| Welded To    |              |                               |              |      |      |        |      |

| VARIABLES          | Actual Values | Qualification Limits |
|--------------------|---------------|----------------------|
| Type of weld joint |               |                      |
| Base metal         |               |                      |

|                     | Groove | Fillet | Clad / Hardf. |  | Groove | Fillet | Clad / Hardf. |
|---------------------|--------|--------|---------------|--|--------|--------|---------------|
| Sheet Thickness     |        |        |               |  |        |        |               |
| Pipe/Tube Thickness |        |        |               |  |        |        |               |
| Pipe/Tube Diameter  |        |        |               |  |        |        |               |

|                                  |  |
|----------------------------------|--|
| Welding Process                  |  |
| Type (Manual/Mech./Auto./Semi. ) |  |
| Backing                          |  |
| AWS Filler Metal Specification   |  |
| AWS Classification               |  |
| F-Number                         |  |
| Consumable Insert                |  |
| Weld deposit thickness           |  |
| Position                         |  |
| Groove – Sheet & Tube ≥ 1"       |  |
| Groove – Tube < 1"               |  |
| Fillet – Sheet & Tube            |  |
| Clad / Hardfacing                |  |
| Vertical Progression             |  |
| Backing Gas                      |  |
| OFW Fuel Gas                     |  |
| GMAW Transfer Mode               |  |
| GTAW welding current/polarity    |  |

**TEST RESULTS**

| Type of Test | Acceptance Criteria | Result | Remarks |
|--------------|---------------------|--------|---------|
|              |                     |        |         |
|              |                     |        |         |
|              |                     |        |         |
|              |                     |        |         |

**CERTIFICATION**

| Test Conducted by |  |
|-------------------|--|
| Laboratory        |  |
| Test number       |  |
| File number       |  |

We, the undersigned, certify that the statements in this record are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of AWS D17.1/D17.1M (\_\_\_\_) Specification for Fusion Welding for Aerospace Applications.

Manufacturer or Contractor \_\_\_\_\_ Authorized By \_\_\_\_\_

**Figure F.3—Example of a Performance Qualification Test Record**

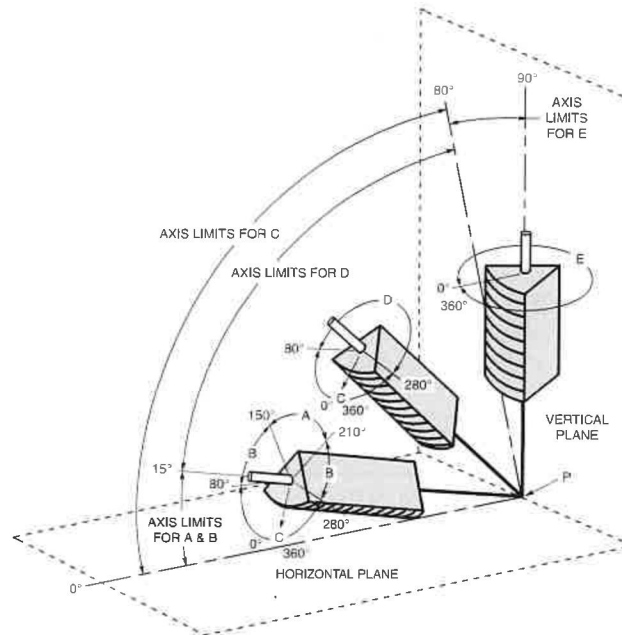
AWS D17.1/D17.1M:2024

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## Annex G (Informative)

### Qualified Positions for Production Welding

This annex is not part of this standard, but is included for informational purposes only.



Tabulation of Positions of Groove Welds

| Position   | Diagram Reference | Inclination of Axis | Rotation of Face |
|------------|-------------------|---------------------|------------------|
| Flat       | A                 | 0° to 15°           | 150° to 210°     |
| Horizontal | B                 | 0° to 15°           | 80° to 150°      |
|            |                   |                     | 210° to 360°     |
| Overhead   | C                 | 0° to 80°           | 0° to 80°        |
|            |                   |                     | 280° to 360°     |
| Vertical   | D                 | 15° to 80°          | 80° to 280°      |
|            | E                 | 80° to 90°          | 0° to 360°       |

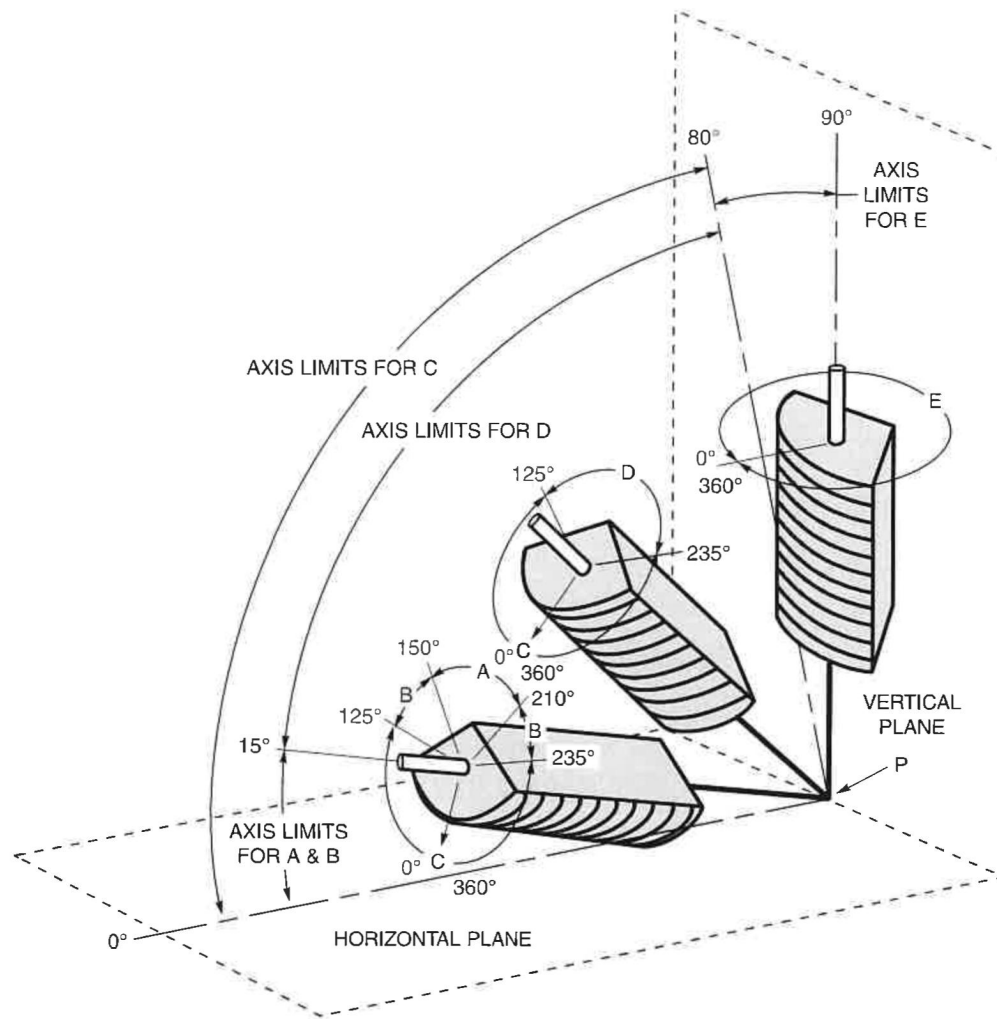
#### NOTES:

1. The horizontal reference plane is always taken to lie below the weld under construction.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference point.
3. The axis of rotation of the weld face is determined by a line perpendicular to the weld face at its center which passes through the weld axis.  
The reference position (0°) of rotation of the weld face invariably points in the direction opposite to that in which the weld axis angle increases.  
When looking at point "P," the angle of rotation of the weld face is measured in a clockwise direction from the reference position (0°).

Source: Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions*, Figure B.16A, American Welding Society.

Figure G.1—Positions of Production Groove Welds

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| Tabulation of Fillet Welds |                   |                     |                  |
|----------------------------|-------------------|---------------------|------------------|
| Position                   | Diagram Reference | Inclination of Axis | Rotation of Face |
| Flat                       | A                 | 0° to 15°           | 150° to 210°     |
| Horizontal                 | B                 | 0° to 15°           | 125° to 150°     |
|                            |                   |                     | 210° to 235°     |
| Overhead                   | C                 | 0° to 80°           | 0° to 125°       |
|                            |                   |                     | 235° to 360°     |
| Vertical                   | D                 | 15° to 80°          | 125° to 235°     |
|                            | E                 | 80° to 90°          | 0° to 360°       |

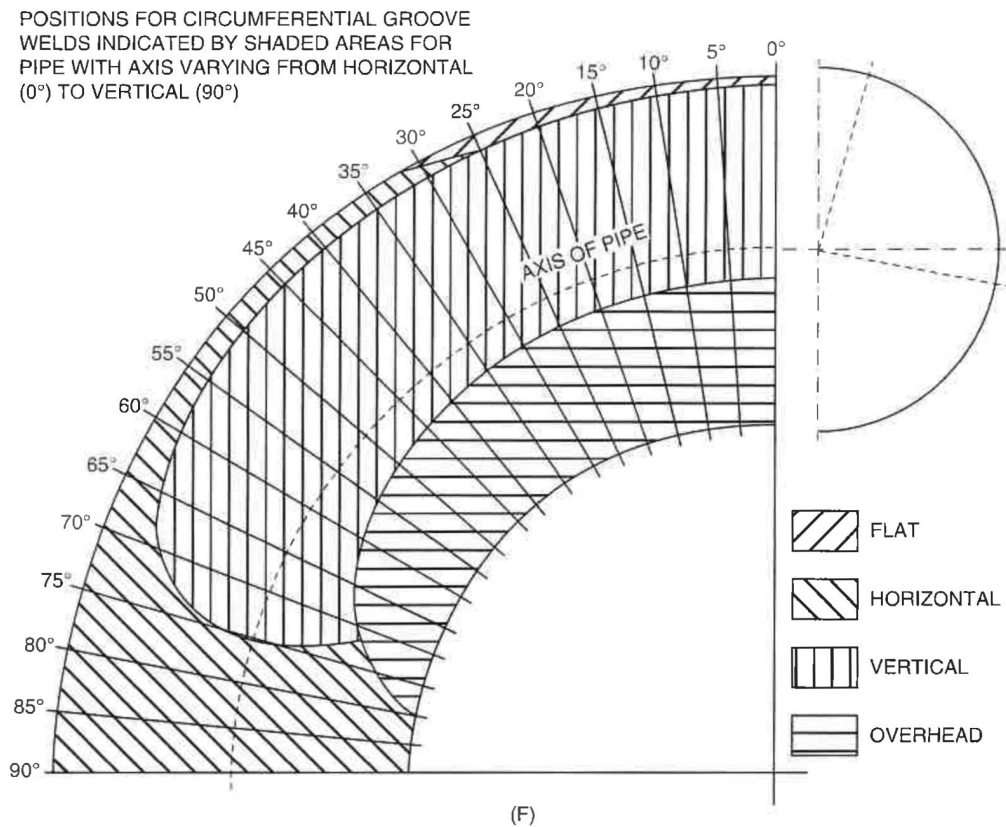
**NOTES:**

1. The horizontal reference plane is always taken to lie below the weld under construction.
2. The inclination of the weld axis is measured from the horizontal reference plane toward the vertical reference point.
3. The axis of rotation of the weld face is determined by a line perpendicular to the weld face at its center which passes through the weld axis. The reference position (0°) of rotation of the weld face invariably points in the direction opposite to that in which the weld axis angle increases. When looking at point "P," the angle of rotation of the weld face is measured in a clockwise direction from the reference position (0°).

Source: Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions*, Figure B.16B, American Welding Society.

**Figure G.2—Positions of Production Fillet Welds**





Source: Reproduced from AWS A3.0M/A3.0:2010, *Standard Welding Terms and Definitions*, Figure B.16C, American Welding Society.

**Figure G.3—Production Welding Position Diagram for Groove Welds in Pipe or Tube**

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## Annex H (Informative)

### Common Acronyms Used in this Standard

This annex is not part of this standard but is included for informational purposes only.

HAZ — Heat Affected Zone

MT — Magnetic Testing or Magnetic Particle Examination

MRB—Material Review Board

NDE — Nondestructive Examination

OEM—Original Equipment Manufacturer

PQR — Procedure Qualification Record

PT — Penetrant testing or penetrant examination

PWHT — Postweld Heat Treatment

RT — Radiographic Testing or radiographic examination

UT—Ultrasonic Testing

WPS — Welding Procedure Specification

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## Annex I (Informative)

### Recommended Shielding Gases and Filler Metals

This annex is not part of this standard but is included for informational purposes only.

**11 Scope.** The following information and tables are provided for reference and are based on common industry practice.

**12 Shielding Gas.** Although Table I.1 lists many types, it does not include various ratios or every composition that could be encountered.

**13 Filler Metals.** The filler material information provided in Tables I.2(a), I.2(b), I.2(c) is for general guideline use and shall not be used for filler metal selection without direction from the Engineering Authority.

**Table I.1**  
**Recommended Shielding Gases for Welding<sup>a</sup>**

| Material                 | Gas <sup>b</sup> |    |       |                                |      |                |                 |                    |
|--------------------------|------------------|----|-------|--------------------------------|------|----------------|-----------------|--------------------|
|                          | Ar               | He | Ar-He | Ar-O <sub>2</sub> <sup>c</sup> | Ar-H | N <sub>2</sub> | CO <sub>2</sub> | Ar-CO <sub>2</sub> |
| Aluminum and Its Alloys  | X                | X  | X     |                                |      |                |                 |                    |
| Cobalt and Its Alloys    | X                | X  | X     |                                | X    |                |                 |                    |
| Copper and Its Alloys    | X                | X  | X     |                                |      |                |                 |                    |
| Magnesium and Its Alloys | X                | X  | X     |                                |      |                |                 |                    |
| Nickel and Its Alloys    | X                | X  | X     |                                |      |                |                 |                    |
| Stainless Steel Alloys   | X                | X  | X     | X                              |      | (Note d)       |                 |                    |
| Plain Carbon Steels      | X                | X  | X     | X                              |      |                | (Note e)        | (Note e)           |
| Low Alloy Steels         | X                | X  | X     | X                              |      |                |                 | (Note e)           |
| Titanium and Its Alloys  | X                | X  | X     |                                |      |                |                 |                    |

<sup>a</sup> Refer to paragraph 6.2.3.2.

<sup>b</sup> Gas Compositions and mixtures shall comply with Table 6.1.

<sup>c</sup> 8% oxygen maximum.

<sup>d</sup> Recommended for backing only.

<sup>e</sup> Only recommended on plain carbon steels or low alloy steels with a maximum of 0.25% nominal carbon.

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**Table I.2(a)  
Filler Metal Guidelines for Welding Aluminum Alloys<sup>a</sup>**

| Base Metal | Filler Material        | Filler Material Specification |
|------------|------------------------|-------------------------------|
| A91100     | A91100, A94043 or 4943 | AWS A5.10/A5.10M              |
| A93003     | A91100, A94043 or 4943 | AWS A5.10/A5.10M              |
| A92219     | A92319                 | AMS4191 or AWS A5.10/A5.10M   |
| A95052     | A95356, A94043 or 4943 | AWS A5.10/A5.10M              |
| A96013     | A94043 or 4943         | AWS A5.10/A5.10M              |
| A96061     | A94043, A95356 or 4943 | AWS A5.10/A5.10M              |

<sup>a</sup> Refer to F6.12 and 6.12.

**Table I.2(b)  
Filler Metal Guidelines for Welding Titanium Alloys<sup>a</sup>**

| Base Metal             | Filler Material | Filler Material Specification |
|------------------------|-----------------|-------------------------------|
| R50250                 | R50120          | AMS4951                       |
| R50400, R50550, R52400 | R52400          | AWS A5.16/A5.16M              |
| R56320                 | R56320          | AWS A5.16/A5.16M              |
| R54520                 | R54520          | AMS4953                       |
|                        | R54520          | AWS A5.16/A5.16M              |
| R56400 or R56402       | R56408          | AMS4956 or AWS A5.16/A5.16M   |

<sup>a</sup> Refer to F6.12 and 6.12.

**Table I.2(c)  
Filler Metal Guidelines for Welding Stainless Steels and  
Heat-Resistant Alloys<sup>a</sup>**

| Base Metal          | Filler Material  | Filler Material Specification |
|---------------------|------------------|-------------------------------|
| S30403 and S31603   | S30883           | AWS A5.9/A5.9M                |
| S32100 and S34700   | S32180 or S34780 | AWS A5.9/A5.9M                |
| K66286              | A286             | AMS5804 or AMS5805            |
| S21900              | S21980           | AWS A5.9/A5.9M                |
| S13800              | S13559           | AMS5840                       |
| S15700              | S15789           | AMS5812                       |
| S15500              | S15500 or S17480 | AMS5826 or AWS A5.9/A5.9M     |
| S17400              | S17480           | AMS5825 or AWS A5.9/A5.9M     |
| S17700              | S17780           | AMS5824                       |
|                     | S15789           | AMS5812                       |
| N06600              | N06062           | AWS A5.14/A5.14M              |
| N06625              | N06625           | AMS5837                       |
|                     | N10004           | AMS5786 or AWS A5.14/5.14M    |
| N07718              | N07718           | AMS5832                       |
| N07750 <sup>b</sup> | N06052           | AWS A5.14/A5.14M              |

<sup>a</sup> Refer to F6.12 and 6.12.

<sup>b</sup> Refer to Annex D for a cross reference between alloy numbers, proprietary trade names and UNS numbers.

## **Annex J (Informative)**

### **Requesting an Official Interpretation on an AWS Standard**

This annex is not part of this standard but is included for informational purposes only.

#### **J1. Introduction**

The following procedures are here to assist standard users in submitting successful requests for official interpretations to AWS standards. Requests from the general public submitted to AWS staff or committee members that do not follow these rules may be returned to the sender unanswered. AWS reserves the right to decline answering specific requests; if AWS declines a request, AWS will provide the reason to the individual why the request was declined.

#### **J2. Limitations**

The activities of AWS technical committees regarding interpretations are limited strictly to the interpretation of provisions of standards prepared by the committees. Neither AWS staff nor the committees are in a position to offer interpretive or consulting services on (1) specific engineering problems, (2) requirements of standards applied to fabrications outside the scope of the document, or (3) points not specifically covered by the standard. In such cases, the inquirer should seek assistance from a competent engineer experienced in the particular field of interest.

#### **J3. General Procedure for all Requests**

**J3.1 Submission.** All requests shall be sent to the Managing Director of AWS Standards Development Division. For efficient handling, it is preferred that all requests should be submitted electronically through [standards@aws.org](mailto:standards@aws.org). Alternatively, requests may be mailed to:

Managing Director  
Standards Development  
American Welding Society  
8669 NW 36 St, #130  
Miami, FL 33166

**J3.2 Contact Information.** All inquiries shall contain the name, address, email, phone number, and employer of the inquirer.

**J3.3 Scope.** Each inquiry shall address one single provision of the standard unless the issue in question involves two or more interrelated provisions. The provision(s) shall be identified in the scope of the request along with the edition of the standard (e.g., D1.1:2006) that contains the provision(s) the inquirer is addressing.

**J3.4 Questions(s).** All requests shall be stated in the form of a question that can be answered 'yes' or 'no.' The request shall be concise, yet complete enough to enable the committee to understand the point of the issue in question. When the point is not clearly defined, the request will be returned for clarification. Sketches should be used whenever appropriate, and all paragraphs, figures, and tables (or annexes) that bear on the issue in question shall be cited.

**J3.5 Proposed Answer(s).** The inquirer shall provide proposed answer(s) to their own question(s).

**J3.6 Background.** Additional information on the topic may be provided but is not necessary. The question(s) and proposed answer(s) above shall stand on their own without the need for additional background information.

#### **J4. AWS Policy on Interpretations**

The American Welding Society (AWS) Board of Directors has adopted a policy whereby all official interpretations of AWS standards are handled in a formal manner. Under this policy, all official interpretations are approved by the technical committee that is responsible for the standard. Communication concerning an official interpretation is directed through the AWS staff member who works with that technical committee. The policy requires that all requests for an official interpretation be submitted in writing. Such requests will be handled as expeditiously as possible, but due to the procedures that must be followed, some requests for an official interpretation may take considerable time to complete.

#### **J5. AWS Response to Requests**

Upon approval by the committee, the interpretation is an official interpretation of the Society, and AWS shall transmit the response to the inquirer, publish it in the *Welding Journal*, and post it on the AWS website.

#### **J6. Telephone Inquiries**

Telephone inquiries to AWS Headquarters concerning AWS standards should be limited to questions of a general nature or to matters directly related to the use of the standard. The *AWS Board Policy Manual* requires that all AWS staff members respond to a telephone request for an official interpretation of any AWS standard with the information that such an interpretation can be obtained only through a written request. Headquarters staff cannot provide consulting services. However, the staff can refer a caller to any of those consultants whose names are on file at AWS Headquarters.



**List of AWS Documents on Welding in the Aircraft and Aerospace Industries**

| <b>Designation</b> | <b>Title</b>                                                                                 |
|--------------------|----------------------------------------------------------------------------------------------|
| AWS D17.1/D17.1M   | <i>Specification for Fusion Welding for Aerospace Applications</i>                           |
| AWS D17.2/D17.2M   | <i>Specification for Resistance Welding for Aerospace Applications</i>                       |
| AWS D17.3/D17.3M   | <i>Specification for Friction Stir Welding Of Aluminum Alloys for Aerospace Applications</i> |

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